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AMERICAN ROCKET SOCIETY

Rocketry . . . . . Jet Propulsion Sciences . . . . . Astronautics

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Earth Satellite Issue

ARS–ASME SEMI-ANNUAL MEETING CLEVELAND, OHIO, JUNE 17–21 SEE PAGE 393

NEW MEMBERSHIP ROSTER COMING OUT IN JULY (FOR DETAILS, SEE PAGE 402)

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Jet Propulsion, the Journal of the American Rocket Society, is devoted to the advancement of the field of jet propulsion through the publication of original papers disclosing new knowledge and new developments. The term "jet propulsion" as used herein is understood to embrace all engines that develop thrust by rearward discharge of a jet through a nozzle or duct; and thus it includes systems utilizing atmospheric air and underwater systems, as well as rocket engines. Jet Propulsion is open to contributions, either fundamental or applied, dealing with specialized aspects of jet and rocket propulsion, such as fuels and propellants, combustion, heat transfer, high temperature materials, mechanical design analyses, flight mechanics of jet-propelled vehicles, astronautics, and so forth. Jet Propulsion endeavors, also, to keep its subscribers informed of the affairs of the Society and of outstanding events in the rocket and jet propulsion field.

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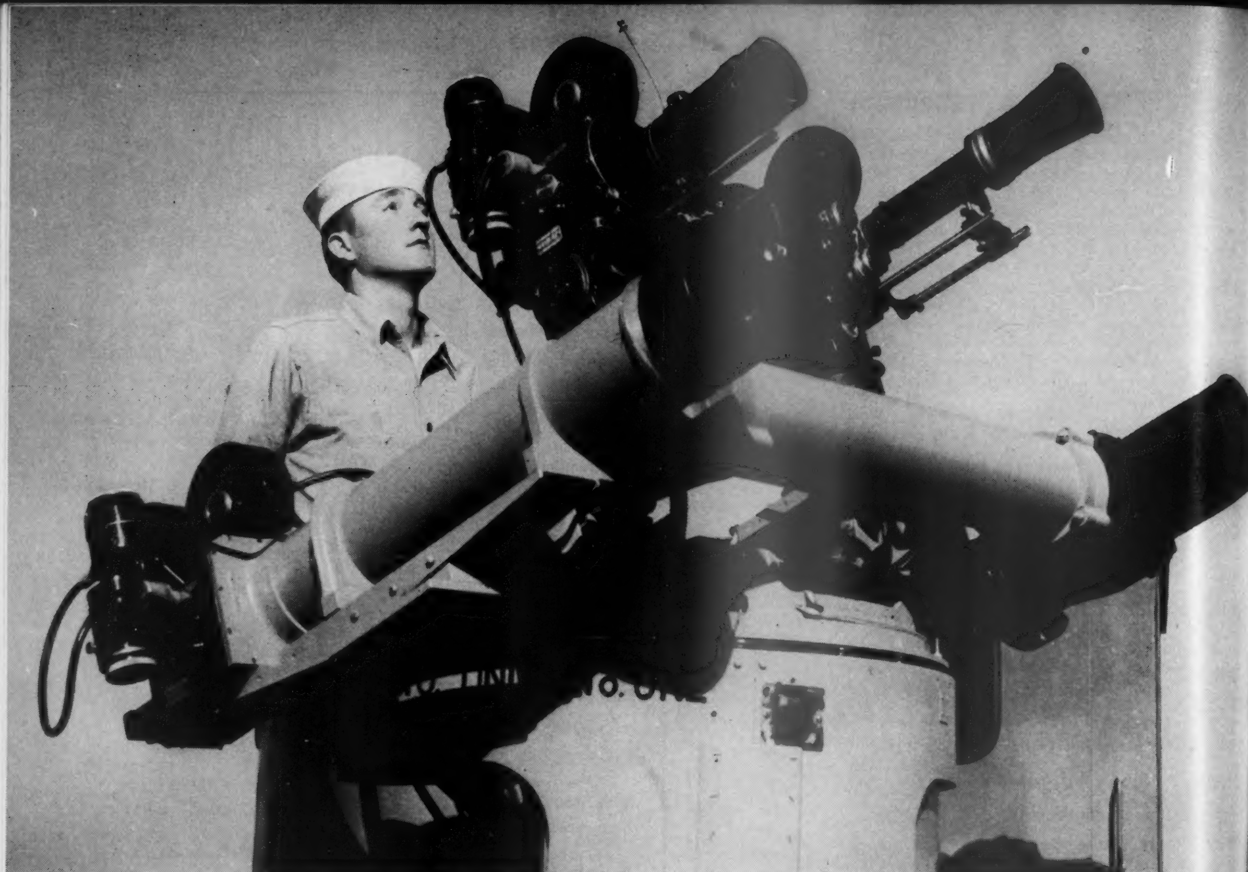


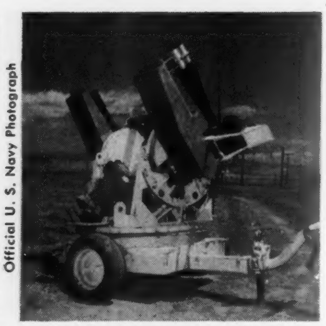
Multiple Mitchell Cameras on Mobile Turret at U. S. Naval Air Missile Test Center, Point Mugu, Calif. Seventeen 35mm and five 16mm Mitchells are used here.

CAMERA BECOMES BASIC RESEARCH TOOL

Official U. S. Army Photograph

200 Mitchell Cameras, mostly high-speed models, are in use here at White Sands Proving Ground, New Mexico.

Official U. S. Navy Photograph



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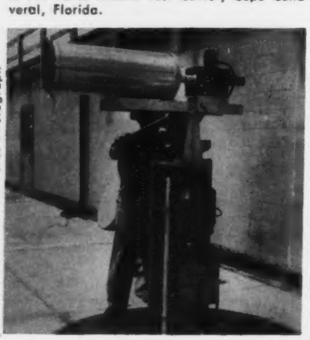
Mitchell Telephoto Tracking Camera in use at Air Force Missile Test Center, Cape Canaveral, Florida.

Official U. S. Air Force Photograph



One of 12 Mitchell cameras used to track missiles at Holloman Air Development Center, Alamogordo, New Mexico.

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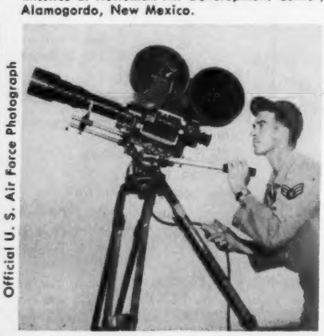

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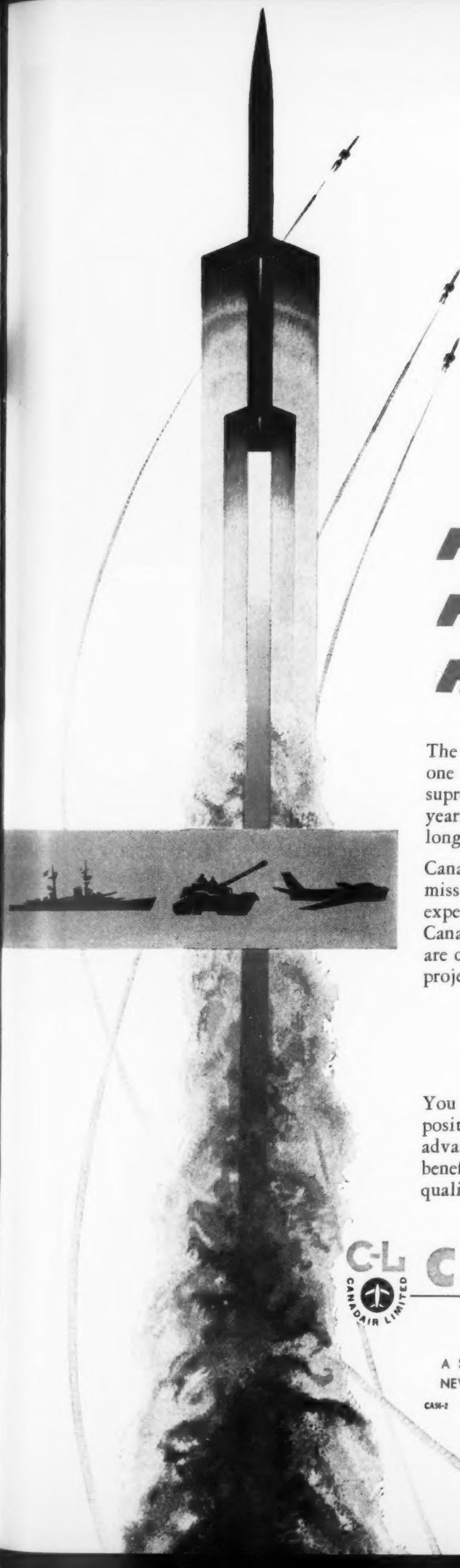

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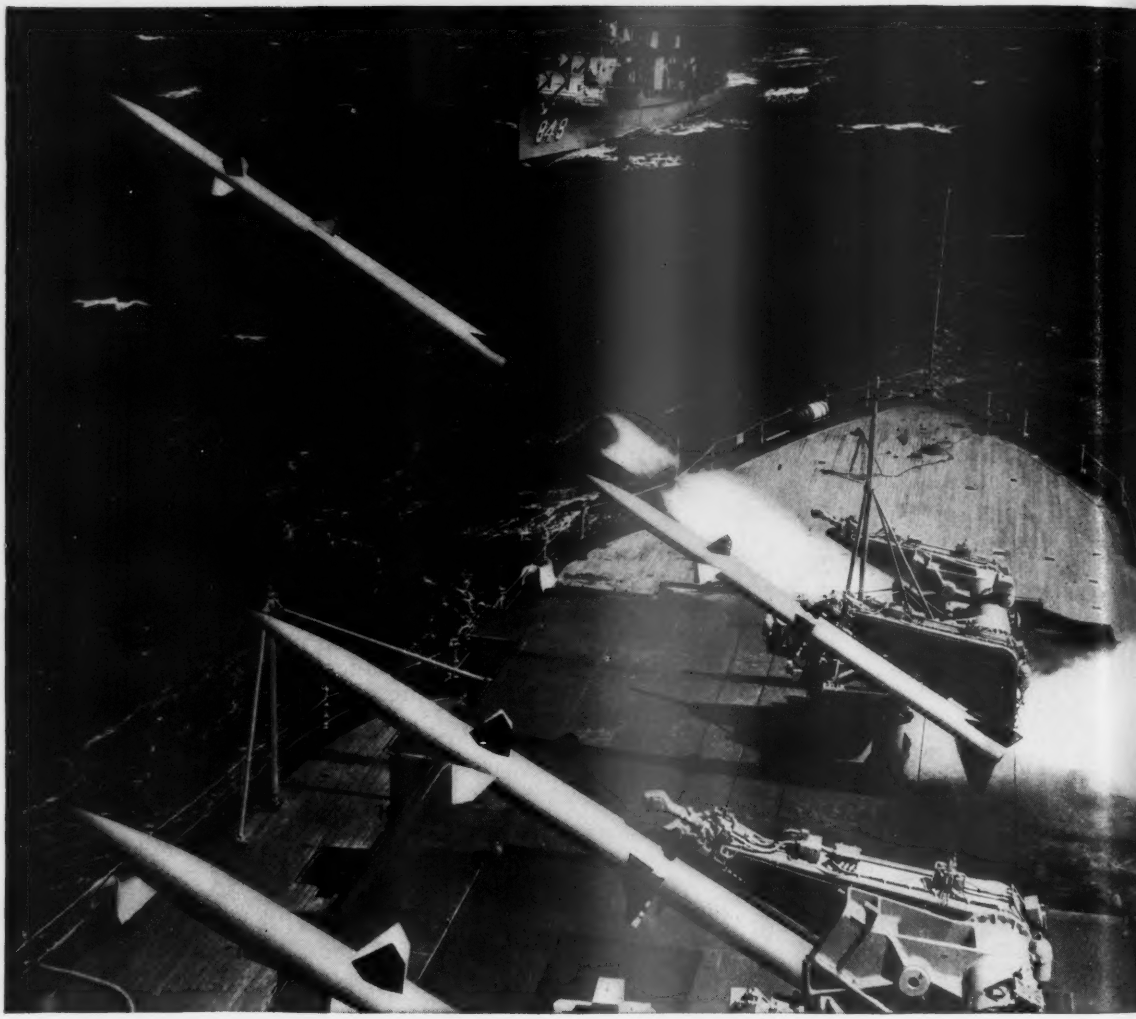

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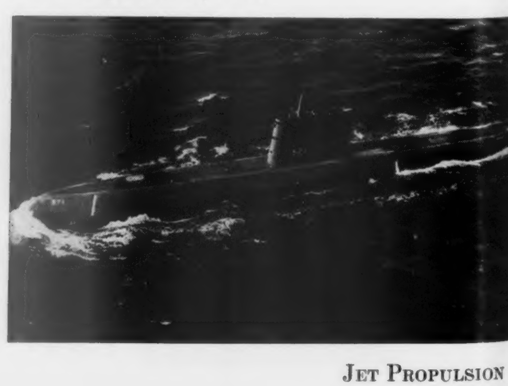

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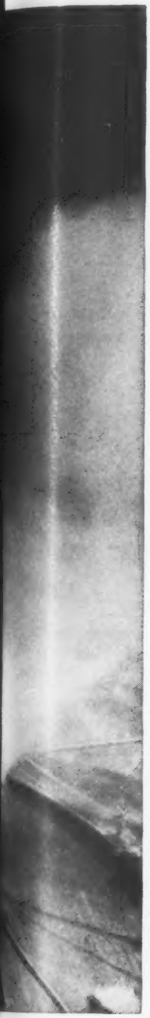

Important Components from ALCO are Installed in Leading Weapons of All Three Services; ALCO also Serves as Prime Contractor

ALCO-built weapons components range from heavy final drives for tanks to air flasks and propellant chambers for missiles, to complicated and precise recoil mechanisms. For the M48A2 medium tank, ALCO also serves as prime contractor, doing complete assembly of items from 1500 suppliers.

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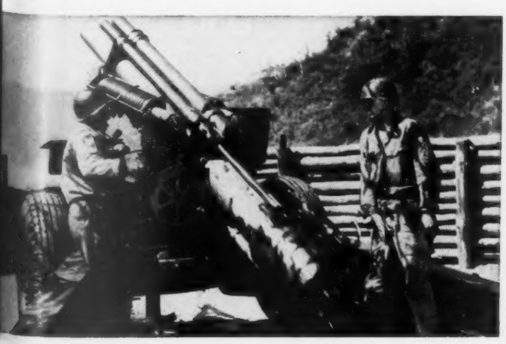
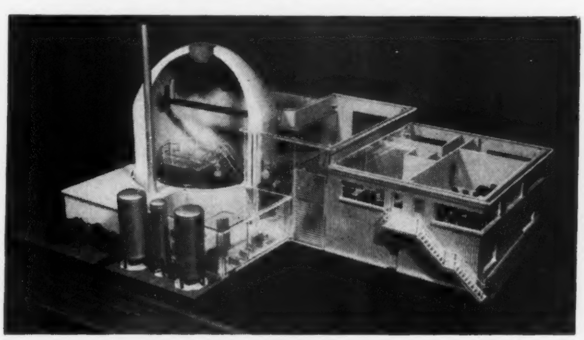
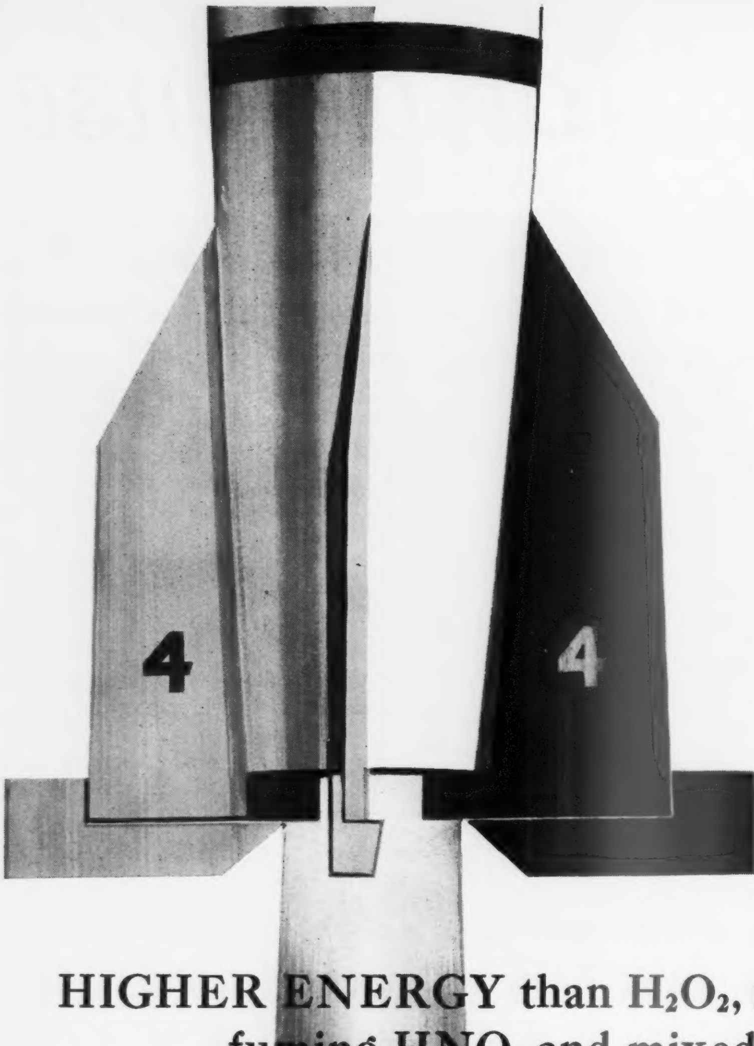
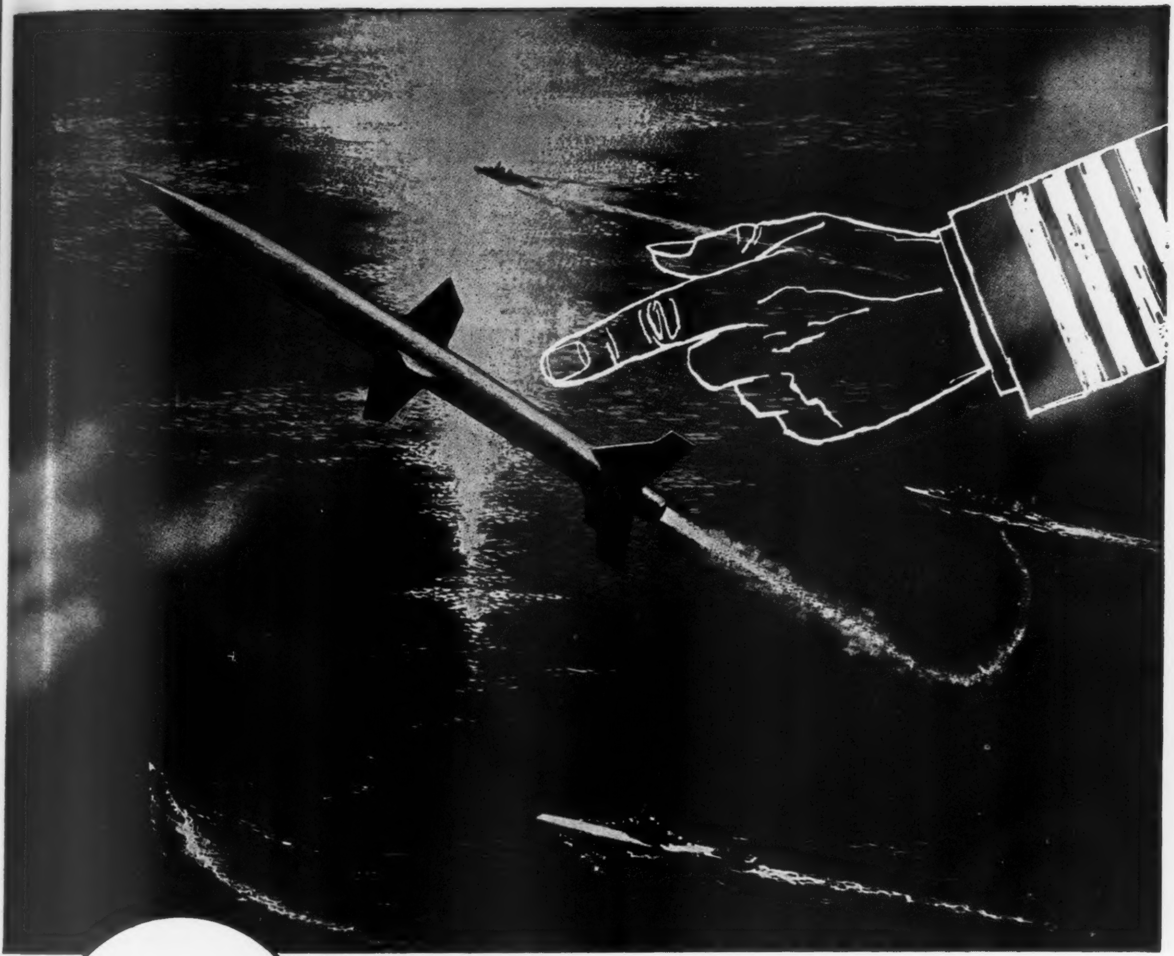


ARMY PACKAGE POWER REACTOR, not a weapon, will generate power at Fort Belvoir, Va. Future APPR's will power remote installations. ALCO holds prime contract for unit, won in competition with 17 top U. S. manufacturers. APPR will be erected by ALCO by early 1957.







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MAY 1956

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Journal of the
AMERICAN ROCKET SOCIETY

Editor-in-Chief

MARTIN SUMMERFIELD

Lifetimes of Satellites in Near-Circular and Elliptic Orbits

N. V. PETERSEN[1]

Sperry Gyroscope Company, Great Neck, N. Y.

The problem of determining the approximate lifetime or duration for simple satellite configurations as influenced by the gravitational field and atmospheric envelope of the Earth is considered. The equations of motion for the case of initial near-circular and elliptic orbits for spherical and conical body shapes exposed to the rarefied atmosphere are shown. An approximate solution for the differential equations of motion is presented for the special case of diffuse reflection for free molecule flow. Lifetimes for small instrumented satellites having a mass-area ratio of 1 slug/ft², satellite bodies having extremely small mass-area ratios of 0.1 slug/ft², and for large vehicles having mass-area ratios of about 10 slugs/ft² are shown. The lifetimes of satellites increases markedly with altitude and mass-area ratio.

Nomenclature

A = position of apogee
a = $g_0R_0^2$
b = constant
C_d = drag coefficient
c = constant
c_t = mean molecular speed
d = mean diameter of gas particle
E_d = drag energy
E_k = kinetic energy
E_p = potential energy
E_t = total energy
F_c = centrifugal force
F_d = drag force
F_g = gravitational force
f = fraction of gas particle stream absorbed
g = acceleration of gravity
g_0 = Earth surface value of acceleration of gravity
h = orbital altitude above Earth surface
°K = absolute temperature degrees Kelvin
l = molecular mean free path length
L = characteristic length of vehicle
m = mass
M_E = Earth's mass
M = molecular speed
m = molecular or particle density
P = position of perigee
r = altitude above Earth's center
R_0 = mean radius of Earth
Δr = increment of altitude
$\ddot{r}$ = radial acceleration
$\dot{r}$ = radial velocity
S = reference area
t = time
t_L = satellite lifetime
τ = orbital period for stationary Earth
τ_e = rotational period of Earth
V = path velocity
$\dot{V}$ = path acceleration
V_N = normal velocity
V_R = radial velocity
ΔV = drag attenuation of path velocity
$V_c = V_s$ = circular or satellite velocity
α_i = angle of incidence
δ = boundary layer thickness
σR = density ratio Rand (Ref. 7) data
σG = density ratio Geophysical (Ref. 8) data
ρ = density variation
γ = gravitational constant
β = flight path angle
m/a = mass-area ratio

I Introduction

Recent technological developments in the fields of rocket propulsion, guidance, and related sciences indicate that feasibility of circular motion about the Earth can readily be shown. Flight speeds in excess of that required for circularity at the Earth's surface, that is, velocities greater than about five miles per sec, will permit the establishing of a permanent or near-permanent orbit about the Earth. The first orbiters, or satellite vehicles, to be launched will undoubtedly be relatively small instrumented research vehicles developed for the prime objective of obtaining extra-atmospheric data such as cosmic ray intensities, solar radiation, intensity of Earth's reflected light, Earth's magnetic field, and many others. Additionally, probably the most elementary satellite vehicle, a simple sphere of some arbitrary mass, *m*, would permit the determination of the atmospheric density at extreme altitudes. Through the use of tracking devices, radar or optical, the determination of the trajectory of a sphere initially constrained to a circular or near-circular path about the Earth and continuously influenced by the drag existing in the rarefied atmosphere would permit the density variation to be ascertained precisely. Perturbations of the orbit would provide for gravity determinations and triangulations of orbit position would give precise land surveys over large bodies of water. This paper considers the particular aspect of estimating the lifetime, t_L, or duration, for a simple satellite configuration from an arbitrary initial near-circular or elliptic constraint at launch to decay to the surface of the Earth. Al-

Presented at the ARS 25th Anniversary Annual Meeting, Nov. 14–18, 1955, Chicago, Ill.

[1] Engineer, Airborne Weapons Systems.

though the atmospheric density assumed to exist at extreme altitudes, above 100 miles, though relatively small when compared to the Earth's surface value, will over a long period of time, influence the flight path or orbit of a satellite vehicle. The integrated effect of the drag will gradually reduce the orbital altitude with the more dense regions of the atmosphere, finally terminating the initially established circular or elliptic motion.

Factors affecting the near-circular orbit lifetime, as shown by the equations of motion, are the density variation, ρ, the drag coefficient, c_d, occurring for the condition of free molecule flow, and the gravitational potential of the Earth, g.

For the case of eccentric or elliptic orbits, the orbit lifetime is similarly influenced by the same factors as for circular flight. However, the problem is further complicated by the periodic variation in density with the altitude extremes of the orbit, that is, apogee and perigee. For a highly eccentric orbit, the apogee altitude would be sufficiently large to permit the assumption of zero drag at apogee to be a reasonable approximation. Consequently, the satellite would undergo a retardation only at perigee where it encounters the denser region of the atmosphere, thus consuming part of its initial total energy E_T. For an elliptic orbit having an initial apogee at 1000 miles and perigee at 100 miles considering the drag retardation occurring only at perigee will reduce the apogee and perigee point on each successive revolution around the Earth. A further approximation to the determination of the elliptic orbit lifetime is made by assuming that continued orbiting of the vehicle does not appreciably reduce the point of perigee. That is, the perigee point remains fixed throughout the orbit decay with the apogee point being reduced by an increment, Δh_A, proportional to the drag energy, E_d, occurring during immersion in the atmosphere.

This paper shows (a) the general characteristics of circular motion neglecting the drag effects, (b) the structure of the atmosphere, (c) the free molecule flow drag considerations, and (d) the equations of motion for a satellite vehicle on circular and elliptic orbits. An approximate solution to the nonlinear differential equations of motion for near-circular constraint is shown.

Some effort has been directed toward determining the orbit lifetimes for various satellite configuratious. Saenger (1)[2] and Ehricke (2) have estimated the altitude loss per revolution, Δr/rev and the ratio of the velocity attenuation due to drag, to the circular velocity, $\Delta v/v_c$, respectively, for the 22,000-lb supersonic skip-bomber and the 11,000-lb orbital carrier. The orbit lifetimes for the skip-bomber are based on a conservative system with equilibrium existing between the kinetic, potential and drag energies. That is, the reduction in potential energy (gravitational) and the increase in kinetic energy (of motion) is equated to the work of the air drag per revolution. The total lifetime from launch at circularity to the surface is not shown in either of these papers. However, from Saenger, an estimate is made for the special case of the total time for the vehicle to dissipate one per cent of its original altitudes. Singer (3) has shown the estimated lifetimes for the MOUSE for the conditions of circular and slightly eccentric elliptical orbits. The atmospheric characteristics and the technique in solving the equations of motion, however, have not been published. The orbit lifetime is shown to vary markedly with launch altitude and orbit eccentricity. For the elliptic orbits the drag that exists in the region of perigee rapidly adjusts the elliptic path to that of a circular orbit. Lifetimes are estimated for altitudes up to 1000 kilometers for a MOUSE-type vehicle.

Reference is made to the author's earlier paper (4). The lifetimes for spherical satellites having mass-area ratios from 0.1 to 10 were determined for the cases of near-circular orbits. This paper includes the lifetime estimates from (4).

[2] Numbers in parentheses indicate References at end of paper.

Ehricke (5) has recently estimated the lifetimes for spheres with initial orbital altitudes up to 200 miles with the analysis based on a conservative system assuming the kinetic, potential, and drag energies being continuously in equilibrium.

The significance of orbit lifetimes is that the purpose of an orbital device is related to the degree of orbit stability that exists for a given altitude. For low altitude orbiters, for both circular and elliptic cases, the usefulness is limited to short period research studies and refueling and payload transfer. This altitude, as shown in this paper, is perhaps from 100 to 200 miles, or approximately the 90-min orbit. Near-permanent orbits, as required for extended research studies, astronomical observation, long period reconnaissance of the Earth, weather observation and space stations for departure points of extended expeditions, exist at altitudes of 500 to 1000 miles, or near the two-hour orbit (1075 miles). This is assumed to apply for elliptic orbits as well as circular orbits, where perigee occurs at these same minimum altitudes.

The special case of extremely low density satellites, thin metal-foil spheres by Pierce (6), for use as a communication relay station may require for a near-stable orbit altitudes considerably in excess of the two-hour orbit.

II Characteristics of Circular Orbits

The general characteristics of satellite vehicles in circular orbits about the Earth, that is, the satellite velocity and period, can be shown to be simple functions of the Earth's surface value of gravitational acceleration, g_0, the Earth's mean radius, R_0, and the orbital altitude, h. Fig. 1 illustrates these characteristics for orbital altitudes from sea level to 10,000 miles and additionally shows the gravitational acceleration variation.

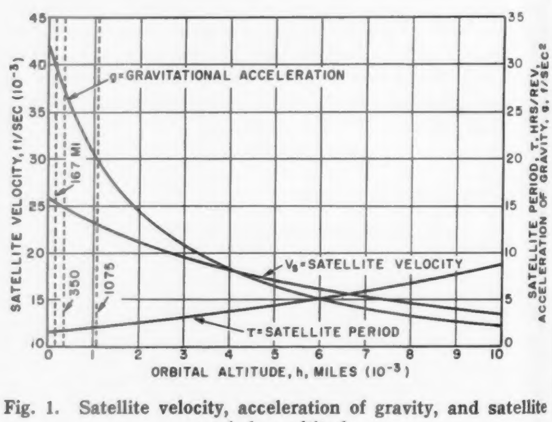

Fig. 1. Satellite velocity, acceleration of gravity, and satellite period vs. altitude

Although Fig. 1 shows orbital altitudes to 10,000 miles, the estimated lifetimes for satellites discussed in this paper will be made at the lower altitudes, principally from 100 miles to 400 miles for circular orbits and from 100 miles to 1000 miles for elliptic orbits. In Fig. 1, the vertical dashed lines show orbits at 167, 350, and 1075 miles. The upper and lower altitude extremes were chosen for the following reasons: (a) h = 167 miles represents the 90-min orbit and is perhaps a probable minimum altitude for the first instrumented satellite probes having useful lifetimes of 1 to 20 days. This altitude is probable lower limit for refueling or payload transfer orbits. (b) h = 1075 miles: Classic two-hour orbit proposed for large manned satellites, space stations, and as departure orbit for interplanetary transits.

The variation of g with altitude as shown in Fig. 1 is expressed by the equation

$$g = g_0 \left(\frac{R_0}{R_0 + h}\right)^2 \qquad [1]$$

This is simply the inverse square law showing the attenuation of the gravitational attraction with altitude above the surface.

The satellite velocity is determined by equating the centrifugal force, F_c, of a vehicle in circular flight about the Earth to the gravitational force, F_g, exerted by the Earth's mass on that of the vehicle. This equilibrium condition for circular flight is then $F_c = F_g$ and is shown by Equation [2]

$$m(R_0 + h)\omega^2 = mg \qquad [2]$$

where

m = vehicle mass

ω = angular velocity of vehicle about the Earth

$(R_0 + h)$ = orbital altitude above Earth center

The substitution of $v = r\omega$ where $r = (R_0 + h)$ and Equation [1] for g then gives the satellite velocity in terms of R_0, g_0, and h as

$$V_s = R_0 \sqrt{\frac{g_0}{R_0 + h}} \qquad [3]$$

As shown by Fig. 1, the satellite velocity, V_s, decreases from the Earth's surface value of about 4.9 mi/sec (25,920 ft/sec), to zero at an infinite altitude. The value for the two-hour orbit has, however, diminished only to about 4.39 mi/sec (23,000 ft/sec).

The orbital period, τ, is expressed similarly as a function of g_0, R_0, and h. For a stationary Earth, the period in terms of V_s is

$$\tau_s = 2\pi \frac{R_0 + h}{V_s} \qquad [4]$$

In terms of orbital altitude, h, Equation [4] becomes

$$\tau_s = \frac{2\pi}{R_0\sqrt{g_0}}(R_0 + h)^{3/2} \qquad [5]$$

Inasmuch as the lifetime of a satellite is directly influenced by its orbital altitude and mass, it is considered pertinent to illustrate the available potential, kinetic, and total energy per unit mass of vehicle, for dissipation by the aerodynamic drag forces as shown in Fig. 2. The total energy existing at any arbitrary orbital altitude is

$$E_t = E_p + E_k \qquad [6]$$

where E_p is the potential energy as obtained by integrating the expression for the work expended in traversing the gravitional field, and E_k is the necessary kinetic energy to maintain circularity about the Earth. The equation for E_p is

$$E_p = \int_{R_0}^{R_0 + h} mgdR \qquad [7]$$

which, for the limits of R_0 and $(R_0 + h)$ and unit mass becomes

$$E_p = R_0 g_0 \left(\frac{h}{R_0 + h}\right) \qquad [8]$$

The kinetic energy, E_k, for unit mass is for circularity then

$$E_k = {}^1/_2 V_s^2 = {}^1/_2 \left(\frac{R_0^2 g_0}{R_0 + h}\right) \qquad [9]$$

As shown by Fig. 2, the potential energy simply increases with altitude, whereas the required kinetic energy diminishes. The total energy existing on orbit per unit mass is then the summation of Equations [8] and [9], or

$$E_t = \frac{R_0 g_0}{2}\left(\frac{R_0 + 2h}{R_0 + h}\right) \qquad [10]$$

Since the limits of the atmosphere extend to extreme altitude, there exists, say for altitudes below 500 miles, sufficient at-

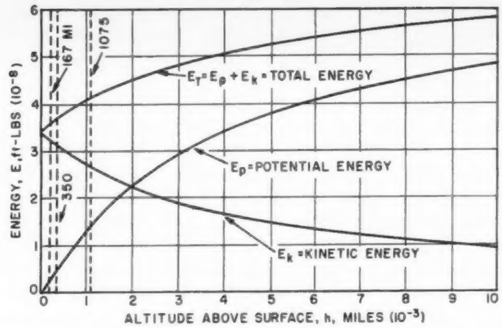

Fig. 2. Potential, kinetic, and total energy required to place unit mass on satellite orbit vs. altitude

mosphere, though tenuous, to effectively retard the motion of a satellite. The total energy shown by Equation [10] to insure or maintain circularity assumes the addition of sufficient thrust forces to overcome the aerodynamic drag. Since the continual expenditure of propellant or energy would normally not be affected, at least for minimum satellites, the orbital energy is then dissipated by the existing drag forces. At altitudes above h = 200 miles, where the density, ρ, from Rand Report R-105 by Grimminger (7) is less than 2.83 $\times$ 10^{-13} slugs/ft^3, the effect of the drag on the vehicle path for a single revolution is insignificant. However, integration of the drag energy over a reasonable length of time considerably affects the satellite orbit. With continued orbiting, the total energy of the satellite may be consumed and ultimately destroyed on flight at the very low altitudes.

III Characteristics of the Atmosphere

The general structure of the Earth's atmosphere from the surface to extreme altitudes has been approximately defined by direct experimental measurements by rocket firings using V-2's; and by Vikings and Aerobee vehicles in the upper-atmosphere physics studies conducted at White Sands Proving Ground and at the equator. Specifically, La Gow (8) gives experimental data on pressure, density, and temperature up to altitudes of 100 miles. Other studies by Whipple (9), Warfield (10), Spitzer (11), Goody (12), Grimminger (7), and others, give experimental and theoretical data of the upper atmosphere. The latter of these by Grimminger was used in part in this paper, since estimated values for the characteristics are given for the altitudes of interest, namely, from 100 miles to 1000 miles. Grimminger presents three atmospheric models, each based on different theories. Since all three models indicate close agreement for all altitudes below 1000 miles, only the characteristics of Model I are discussed. An extrapolation of the experimental data (8) was made due to the significant disagreement with the theoretical data (7). The orbit lifetimes were estimated based on these two references. The structure of the atmosphere is usually assumed to consist principally of four main regions. These are the troposphere (from sea level to about 10 miles), stratosphere (from 10 miles to 40 miles), ionosphere (40 miles to 400 miles) and the exosphere (400 miles extending outward to interplanetary space). The principal region of interest for determination of satellite lifetime is considered to be that of the ionosphere, where the lower region exhibits a sizable density value, though still tenuous relative to that at sea level, sufficient to retard free flight orbital motion to only a fraction of, or at most, a few complete revolutions about the Earth. The upper limit of the ionosphere is perhaps the lower boundary for near-permanent satellite orbits, since the reduction in density becomes vastly less than at the lower limit of this region. The density ratio, σ, at the equator, at 50 miles altitude, is 4.951 $\times$ 10^{-5}, whereas at 500 miles it is 2.68 $\times$ 10^{-12}. Bodies in motion at

these altitudes will then be subjected to drag forces directly proportional to these density ratios. Thus the drag forces on a vehicle at 500 miles will be $\sim 5.4 \times 10^{-6}$ that at the lower limit of 50 miles.

The composition of the ionosphere is considered to be comprised of nearly the same oxygen-nitrogen ratio as at sea level, or about 30 per cent oxygen and 70 per cent nitrogen. However, due to the absorption of ultraviolet solar radiation, the molecular oxygen is dissociated and exists in this region as atomic particles. The nitrogen remains in the molecular state. The mean molecular weight does not vary significantly from about 24 throughout this region. The kinetic temperature, however, varies markedly with altitude. Grimminger (7) assumes that the temperature varies uniformly from the sea-level value out to 10,000°K in free space. This then leads to sizable molecular velocities, consequently affecting the drag coefficient characteristics. A Douglas Aircraft report considers a uniform kinetic temperature of 4000°F existing beyond 400 miles. This would greatly reduce the mean molecular velocity and directly increase the molecular speed ratio M_∞ (where M_∞ is the ratio of the most probable molecular speed and the free stream velocity of the body). This would reduce the drag coefficient somewhat.

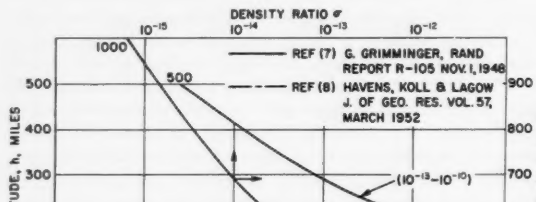

Fig. 3 Atmospheric density ratio vs. altitude

The experimental data available from rocket firings show a considerable variation from that of Grimminger. Direct pressure measurements by rocket firings to 100 miles indicate that the σ_G (where the subscript G refers to the Geophysical data (8) and σ_R refers to the Rand (7) data) value is approximately 1.7×10^{-9}, whereas the Rand data indicate a value of σ_R of 3.3×10^{-8}. This is a variation of about 20. A simple extrapolation of this to higher altitudes was then made. Fig. 3 illustrates the density ratio used in this paper.

IV Aerodynamic Characteristics of Free Molecule Flow

In the rarefied atmosphere of the Earth as existing at extreme altitudes the mechanics of flight are described by the equations of free molecule flow theory or superaerodynamics. Zahm (13) published one of the original papers on the dynamics of rarefied gas flow. Later, Saenger (14, 15), Tsien (16), Snow (17), Ashley (18), Garfunkel (19) and others show detailed analyses of the lift and drag coefficients occurring for various body configurations in high speed flight at extreme altitudes.

Of direct interest in the mechanics of free molecule flow are the particle density, ρ, the mean free path length, l, and the mean molecular speed, c_i.

As shown by Tsien (16), the realm of superaerodynamics is defined by the ratio of the body size (vehicle) to the mean free path length of the particles in the gas flow.

The mean free path length, l, of the gas particles is determined (7, 22) by $l = 1/(\pi\sqrt{2}nd^2)$ where $n = \rho/m$ is the molecular or particle density, or more directly, is the number of gas particles per unit volume. The density, ρ, is the volume mass density, m the mean mass of the gas particles, and d the mean diameter of the gas particles. Thus, the mean free path varies inversely with particle density and the characteristic dimension of the particle. At low altitudes, the density is sufficiently large so that the mean free path length, l, of the gas is much smaller than the characteristic length, L, of the vehicle or the boundary layer thickness, δ (at sea level $l \approx 7.4 \times 10^{-7}$ ft). For conventional gas dynamics (subsonic and supersonic flow) the fluid is considered as a continuous medium with $l \ll L$ or δ with viscosity being an important factor. At higher altitudes, near 40 miles, at the lower limit of the ionosphere, the mean free path length is about one inch. The path length at the altitude of 75 miles becomes about one foot. At higher altitudes the value of l becomes much greater than even the vehicle dimension, where at 150 miles, l = 300 feet, and at the upper limit of the ionosphere at 400 miles the mean free path length is about 2.17×10^5 feet or 40 miles. For the major part of the ionosphere the atmosphere cannot be assumed to be a continuous medium, but must be considered to consist of independent particles. The concept of Reynolds number, which is significant in conventional gas dynamics at low altitudes, considers the relationship of the inertia and viscous forces existing. However, in a rarefied gas flow the viscous action does not apply.

In the tenuous atmosphere surrounding the Earth, the force acting on a surface is based on the assumption that the gas particles are reflected principally, in one of two different ways. These are by the mechanisms of specular or diffuse molecular reflection. The first of these, specular reflection, assumes that the incident stream of particles are elastically reflected from the exposed body surface as shown in Fig. 4(A). This phenomenon is assumed to be applicable only for very low angles of incidence and for bodies having extremely smooth surfaces. The fraction of a molecular stream that is reflected specularly is directly dependent upon the "smoothness" of the reflecting surface, i.e., the roughness height. If the sur-

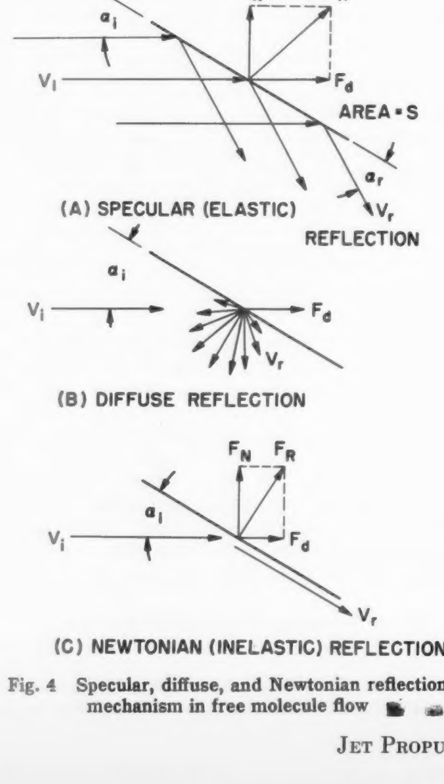

Fig. 4 Specular, diffuse, and Newtonian reflection mechanism in free molecule flow

face projections (roughness) are small compared to the characteristic wavelength of the impinging molecules, specular reflection cannot occur (17). Structural surfaces, though highly polished, are considered rough on the molecular scale. Millikan (20) shows the fraction of the molecular flow that is reflected in this manner is extremely small, less than 3 per cent to 10 per cent, for most materials and surface conditions. The remainder and largest portion of the molecular stream striking the surface, that of diffuse reflection, Fig. 4(B), is assumed to be absorbed by the surface. In this manner the entire kinetic energy is absorbed by the immediate surface layer of the body, thus raising the temperature level of the body. The absorbed molecules are assumed to attain temperature equilibrium with the surface after some finite time interval and then to be emitted at some velocity dependent upon the body temperature. The fraction of molecules absorbed by the surface is expressed as f. Normally, the value of f is from 0.9 to 1.0 with the fraction of the stream reflected specularly being then $(1-f)$. Since the value of $(1-f)$ is usually small, only the diffuse kind of reflection is considered. Fig. 7 shows the drag coefficient for only the diffuse case for spheres and cones.

An additional type of flow suggested (18–20) is similar to Newton's inelastic particle reflection, wherein the molecular stream simply collides with the surface and is deflected only through the body angle α_i. The flow then follows the surface with the normal component of velocity being absorbed and the tangential component being unaffected. This gives then, one half the value for the drag coefficient of specular (elastic) reflection. Fig. 4(C) illustrates this type of flow.

The drag coefficients are shown, from theory, for various body shapes, i.e., spheres (17–19), cones (17–19), cylinders (19), double ogives (19), and flat plates (14, 18, 19). The drag coefficients are shown, in Fig. 5, plotted versus the free molecule Mach number or, molecular speed ratio, $M = V/c_i$. This is the ratio of the free stream velocity, V, to the most probable molecular speed, c, of the impinging stream, where c_i is directly a function of the kinetic temperature of the molecule. Thus $M_\infty = V/v_i = V/\sqrt{2KT}$, where K is the Boltzmann constant and T is the kinetic temperature of the molecule. Since the free stream speeds considered in this paper are near the circular velocity for altitudes of 100 miles to 1000 miles, it is evident that the probable M_∞ is usually from 5 to 10. The drag coefficients thus, for most cases, is slightly greater than 2. For convenience, the value of 2 was used in the computations.

V Equations of Motion (Circular Orbits)

It is assumed that the Earth satellite is initially constrained to near-circularity in the gravitational field of the Earth and subjected to a drag acceleration as influenced by the mass of the satellite and its drag-coefficient velocity relationship. A two-body system is assumed with the orbital motion being coincident with the equatorial plane. This is shown in Fig. 6.

The differential equations of motion, expressed in polar coordinates, are as follows

$$\ddot{r} = r\omega^2 - \frac{a}{r^2} - c\dot{r}V \qquad [11]$$

$$\dot{v} = -\frac{a\dot{r}}{Vr^2} - cV^2 \qquad [12]$$

$$\dot{\omega} = -\frac{2\dot{r}\omega}{r} - cV\omega \qquad [13]$$

$$V^2 = \dot{r}^2 + (r\omega)^2 \qquad [14]$$

Equations [11] to [14], respectively, show the relationship existing for the acceleration of the satellite along the radius vector, $\ddot{r}$; the path acceleration, $\dot{V}$; the angular acceleration of the radius vector, $\dot{\omega}$; and the path velocity, V. The components of Equations [11], [12], and [14] are discussed in the following sections where reference is made to the velocity, force, and acceleration, as shown in Figs. 6 and 7.

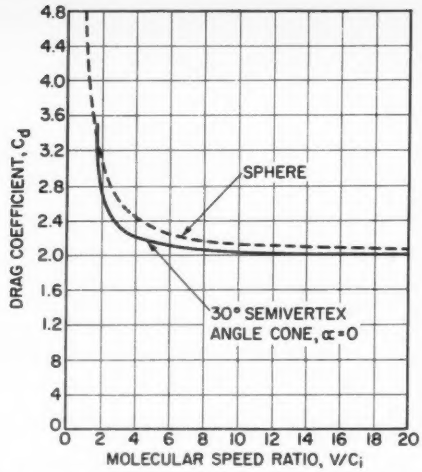

Fig. 5 Diffuse drag coefficient for sphere and cone (NACA TN 2423)

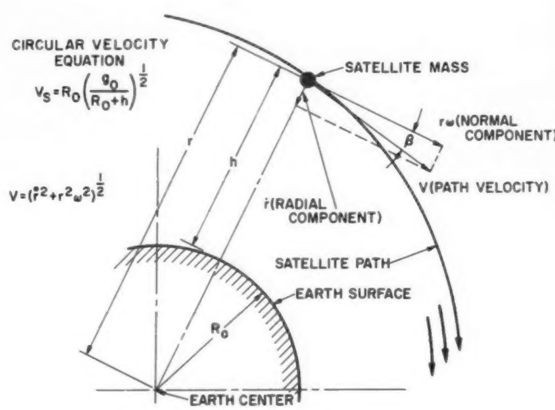

Fig. 6 Satellite velocity diagram

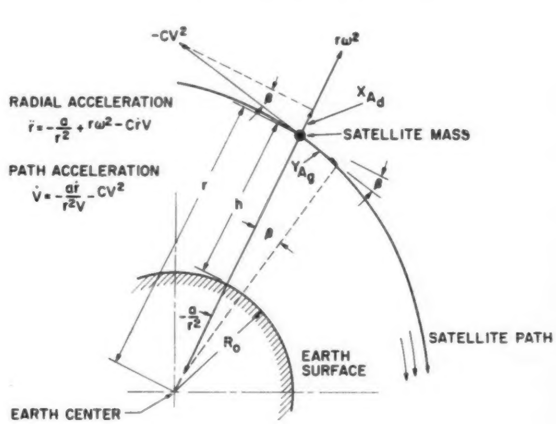

Fig. 7 Satellite acceleration diagram

Path Velocity

The normal and radial components of the path velocity, Equation [12], are illustrated in Fig. 7. The normal component, V_N, is

$$V_N = r\omega \text{ . . . . } [15]$$

and the radial component, V_R is

$$V_R = \dot{r} \text{ . . . . } [16]$$

The path velocity at any instant of time or path location is then

$$V = \sqrt{\dot{r}^2 + r^2\omega^2} \text{ . . . . } [17]$$

As shown in Fig. 6, the path velocity for any orbit is given by Equation [17]. For the special case of circularity, $\dot{r}$ is zero and Equation [3] then shows V to be a simple function of R_0, g_0, and h. However, for the case of an elliptical orbit, with zero drag, $\dot{r}$ would be periodically positive or negative, depending on its orbital position.

Radial and Flight-Path Forces and Acceleration on Body

The velocity and accelerations that exist on the satellite body at any instant due to the gravitational field, the resisting medium (free molecule flow effects), and the centrifugal motion are shown in Figs. 6 and 7, respectively. The three forces act on the body in such a manner as to constrain its motion to a spiral path from the initial conditions of near-circularity. These forces and accelerations are listed below.

Gravitational

The force of acceleration which the Earth exerts on a mass point at a height h, above the surface is

$$F = \frac{\gamma M_e m}{r^2} \text{ . . . . } [18]$$

where

$$\begin{aligned} \gamma = \frac{g_0 R_0^2}{M_e} &= \text{gravitational constant} \\ M_e &= \text{earth mass} \\ m &= \text{satellite mass} \\ R_0 &= \text{earth mean radius} \\ r = (R_0 + h) &= \text{orbital altitude above Earth center} \end{aligned}$$

Substitution of the gravitational constant into Equation [18] then gives

$$F_g = m\frac{g_0 R_0^2}{r^2} \text{ . . . . } [19]$$

and is directed along the radius vector (assumed negative) toward the Earth's center. For unit mass, the radial acceleration due to gravity is

$$\ddot{r}_g = -\frac{F_g}{m} = -\frac{a}{r^2} \text{ . . . . } [20]$$

where $a = g_0 R_0^2$. The flight path component is

$$\dot{V}_g = -\frac{F_g}{m}\sin\beta \text{ . . . . } [21]$$

From the geometry of Fig. 6, the sine of the elevation angle, β, is $\dot{r}/V$. Equation [21] is then

$$\dot{V}_g = -\frac{\dot{r}}{V}\frac{a}{r^2} \text{ . . . . } [22]$$

Centrifugal

The centrifugal force resulting from the curved flight path is simply

$$F_c = mr\omega^2 \text{ . . . . } [23]$$

and is directed along the radius vector, away from the Earth. For the acceleration, this reduces to

$$\ddot{r}_c = +r\omega^2 \text{ . . . . } [24]$$

Drag

The drag force exerted by the molecular stream along the flight path is

$$F_d = C_D S\frac{\rho V^2}{2} \text{ . . . . } [25]$$

where

$$\begin{aligned} V &= \text{free stream velocity} \\ \rho &= \text{density} \\ S &= \text{reference area} \\ C_D &= \text{drag coefficient, specular } C_{D_s} \text{ or diffuse } C_{Dd} \end{aligned}$$

The solution of the equations of motion, Equations [11] to [14], shown in this paper is a step-by-step process, with the drag coefficient assumed as constant and equal to 2 throughout a given interval of altitude r. For unit area, (S = 1 ft^2) and $\rho = \rho_{ave}$ during the interval Equation [22] becomes simply $F_d = c'V^2$, where c' is a constant and equal to $C_D S\rho_{ave}/2 = \rho_{ave}/2$. For a body of unit mass (1 slug) the drag acceleration (assumed negative) along the flight path is

$$\dot{V}_d = \frac{-F_d}{m} = -\frac{c'V^2}{m} = -cV^2 \text{ . . . . } [26]$$

The radial component of the drag acceleration, $\ddot{r}_d$, is

$$\ddot{r}_d = -\frac{F_d}{m}\sin\beta \text{ . . . . } [27]$$

and from geometry

$$\ddot{r}_d = -c\dot{r}V \text{ . . . . } [28]$$

The resultant radial acceleration, $\ddot{r}$, from Equation [11] is the summation of Equations [20], [24], and [30] shown by

$$\ddot{r} = \ddot{r}_g + \ddot{r}_c + \ddot{r}_d \text{ . . . . } [29]$$

The first two terms on the right of Equation [12] represent the general equation of planetary motion. The third term, $-c\dot{r}V$ is the forcing function, due to the drag that perturbs the planetary motion to a spiral path. Further, Equation [11] for the case of zero angular rotation of the body about the Earth, i.e., $\omega = 0$, then becomes the classical representation describing the motion of a body falling in a gravitational field in a resisting medium. Similarly, the flight path acceleration, $\dot{V}$, from Equation [12] is the summation of Equations [22] and [26] shown by

$$\dot{V} = \dot{V}_g + \dot{V}_d \text{ . . . . } [30]$$

The angular acceleration function for $\dot{\omega}$ from Equation [13] is obtained from the expressions for V, $\dot{V}$, and $\ddot{r}$.

Solution of Equation of Motion

It is noted that Equations [11] and [13] are obtainable from the Lagrangian equation of motion (23) for the case of a small perturbation of a system from the initial condition of equilibrium. This considers the kinetic and potential energies, E_k and E_p, of the system as influenced by the dissipation or resistance function (drag) E_d. The Lagrangian equations are given as

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{r}}\right) - \frac{\partial E_k}{\partial r} + \frac{\partial E_d}{\partial \dot{r}} + \frac{\partial E_p}{\partial r} = 0 \text{ . . . . } [31]$$

and

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{\theta}}\right) - \frac{\partial E_k}{\partial \theta} + \frac{\partial E_d}{\partial \dot{\theta}} + \frac{\partial E_p}{\partial \theta} = 0 \text{ . . . . } [32]$$

Substitution of the functions for E_k, E_d, and E_p reduces similarly to the nonlinear equations of [11] and [13] for the case of a resistance function proportional to V^2.

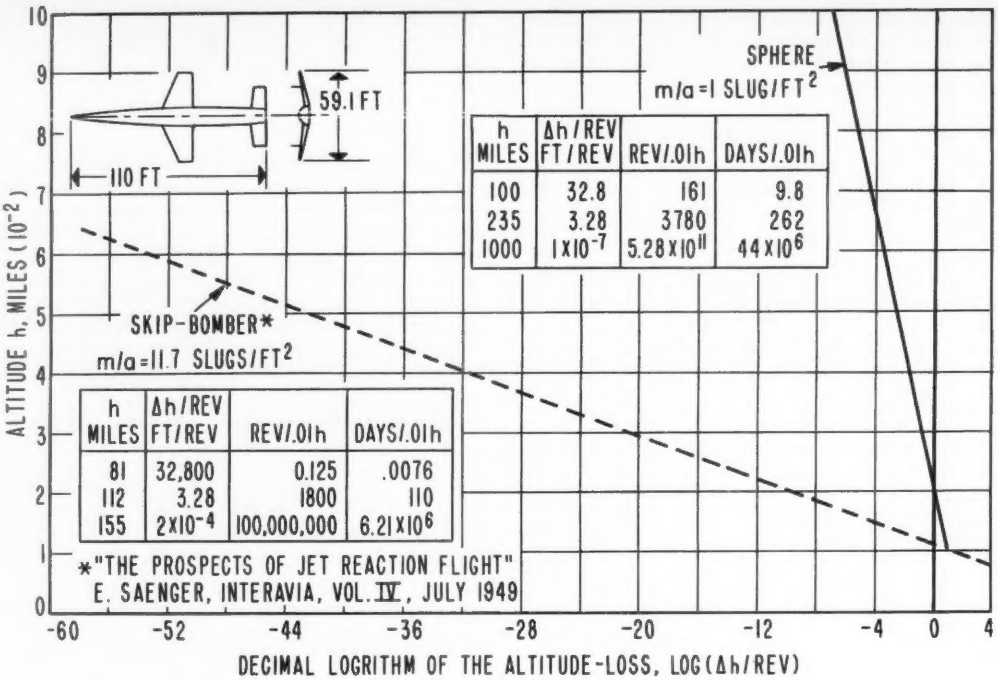

Fig. 8 Altitude-loss (Δh) per revolution for satellite vehicle vs. altitude

A solution in closed form for the nonlinear differential equations [11] and [14] was not affected.

A solution by numerical integration from Milne (23) was initiated; however, insufficient time was available to complete this. Consideration has been given to the solution of the Equations [11] to [14] through use of an analog computer. It is suggested by Forbes (25) that these equations can be solved on the analog computer through the use of alternate equations that eliminate the difficulties due to the small values of r occurring for a near circular orbit. Forbes (25) has studied the case of a powered orbit in free space (with radial accelerations of from 0.001 to 0.0001 g) in effecting transits from the Earth's orbit to another target planet. The problem considered in Forbes' paper is one equation more complicated to mechanize on a computer since the equations of motion of the target planet are required. In this paper, this is not considered. It is anticipated that satellite lifetimes can similarly be determined for the unpowered trajectory with a resistance force acting with correspondingly small radial accelerations.

The approximation for the lifetimes or duration of the skip-bomber from circular orbits has been made by Saenger. This was determined for the special case of equilibrium existing at all times between the kinetic, potential, and drag energies as follows

$$\Delta E_p + \Delta E_k + \Delta E_d = 0 \qquad [33]$$

where the kinetic, potential, and drag energy functions, respectively, from Equations [8], [9], and [25] for circularity for unit mass are

$$E_p + E_k = \frac{R_0 g_0}{2}\left(\frac{R_0 + 2h}{R_0 + h}\right) \qquad [34]$$

$$E_d = \rho g_0 \left(\frac{R_0^2}{R_0 + h}\right) \qquad [35]$$

The energy of drag per revolution is then

$$E_d/\text{rev} = \frac{2\pi \rho g_0 R_0^2}{\text{rev}} \qquad [36]$$

and the number of revolutions for a loss of Δr in altitude is

$$n = \frac{\Delta E_t}{E_d/\text{rev}} \qquad [37]$$

Considering the number of revolutions for a loss of one per cent (0.01) of the original altitude results in the equation

$$\Delta E_t = E_{t_1} - E_{t_2} = \frac{R_0 g_0}{2}\left[\left(\frac{R_0 + 2h_1}{R_0 + h_1}\right) - \left(\frac{R_0 + 2h_2}{R_0 + h_2}\right)\right] \qquad [38]$$

and the equation for the drag energy of

$$E_{d_{ave}}/\text{rev} = \frac{\pi g_0 R_0^2(\rho_1 + \rho_2)}{\text{rev}} \qquad [39]$$

Combining Equations [38] and [39] and using $h_2 = 0.99h$ results in the equation for the altitude loss/rev of

$$\frac{\Delta r}{\text{rev}} = 4000\,\pi \frac{\rho_1}{h_1}(R_0^2 + 1.99R_0h_1 + 0.99h_1^2) \qquad [40]$$

This equation is shown plotted in Fig. 8 for a body of 1 sq ft area and mass of 1 slug. Also shown in this figure is the Δr/rev for the 11-ton skip-bomber (1). The estimated partial lifetime for this vehicle to lose 1 per cent of its altitude is listed in the figure.

From Ehricke (2) the effect of retardation or orbit stability of the 5.5-ton vehicle is discussed. Considering the effect of drag on attenuating the path velocity, the value of $\Delta V/V$ is computed simply by considering the drag effect for one revolution as follows

$$\frac{\Delta V}{V} = \frac{(-cV^2)\,\Delta t}{V} \qquad [41]$$

where Δt = time for one revolution and c is a factor considering the area, mass, and atmospheric density.

An approximate solution to Equations [11] to [14] permitting a step-by-step process suggested by C. Waters[3] is based on the assumption that the path velocity does not vary

[3] Sperry Gyroscope Company.

appreciably for a small interval of Δr. During a given time interval, Δt, the atmospheric drag acting on the vehicle diminishes the orbital altitude from r_0 to r_1 or Δr, and as well, the angular rotation ranges from ω_0 to ω_1. Additionally, the assumption is made that the product cV is constant for a small change in altitude. The equations of motion are then

$$\ddot{r} = r\omega^2 - \frac{a}{r^2} - b\dot{r} \qquad [42]$$

and

$$\dot{\omega} = -\frac{2\dot{r}\omega}{r} - b\omega \qquad [43]$$

Rearranging terms in Equation [43]

$$\frac{\dot{\omega}}{\omega} + 2\frac{\dot{r}}{r} = -b \qquad [44]$$

and integrating results in

$$\log \omega r^2 = -bt + k_1 \qquad [45]$$

and finally

$$\omega r^2 = k_2 e^{-bt} \qquad [46]$$

where $k_2 = e^{k_{1_0}}$ when $t = t_0$

$$\omega_0 r_0^2 = k_2 e^{-bt_0} \qquad [47]$$

Substitution of the value for $k_2 = \omega_0 r_1^2$ into Equation [46] leads to

$$\omega = \omega_0 \frac{r_0^2}{r^2} e^{-b(t-t_0)} \qquad [48]$$

Substituting Equation [48] into Equation [42] then gives the acceleration equation of

$$\ddot{r} = \left[\frac{\omega_0^2 r_0^4}{r^3} e^{-2b(t-t_0)}\right] - \frac{a}{r^2} - b\dot{r} \qquad [49]$$

and

$$r^3\ddot{r} = \omega_0^2 r_0^4 e^{-2b(t-t_0)} - ar - b\dot{r}r^3 \qquad [50]$$

Combining terms and setting the r^3 terms equal to a constant r_0^3, for small values of t, r is nearly equal to r_0. Equation [50] is solvable for r as follows.

$$\ddot{r} + b\dot{r} + \frac{a}{r_0^3} r = \omega_0^2 r_0 e^{-2b(t-t_0)} \qquad [51]$$

Letting

$$r = Ae^{-2b(t-t_0)} \qquad [52]$$

and differentiating twice gives

$$\dot{r} = -2bAe^{-2b(t-t_0)} \qquad [53]$$

and

$$\ddot{r} = -4b^2Ae^{-2b(t-t_0)} \qquad [54]$$

Substituting Equations [52], [53], and [54] into [51] gives

$$4b^2Ae^{-2b(t-t_0)} - 2b^2Ae^{-2b(t-t_0)} + \frac{a}{r_0^3}Ae^{-2b(t-t_0)} = \omega_0^2 r_0 e^{-2b(t-t_0)} \qquad [55]$$

Simplifying Equation [52] and solving for the constant A gives

$$A = \frac{\omega_0^2 r_0}{2b^2 + \dfrac{a}{r_0^3}} \qquad [56]$$

The equations for r and $\dot{r}$, upon substituting the value of A into Equations [52] and [51] are

$$r = r_0 e^{-2b(t-t_0)} \qquad [57]$$

and

$$\dot{r} = -2br_0 e^{-2b(t-t_0)} \qquad [58]$$

The initial values for ω_0 at $t = 0$ is found by substituting into Equation [59] the values for the constants and placing the exponential term = 1. Then

$$\omega_0 = \sqrt{\frac{a}{r_0^3} + 2b^2} \qquad [58]$$

also

$$\dot{r}_0 = -2br_0 = -2c_0V_0r_0 \qquad [59]$$

The latter equation shows that the radial velocity is not zero at $t = 0$, but is directly a function of the drag acceleration, initial velocity, and altitude. The approximate variation of the near circular flight at t_0 from exact circularity is demonstrated by considering the flight path angle, β, that the path velocity vector makes with the horizontal. Thus, $\sin \beta = \dot{r}/V$ and for small angles $\beta = \dot{r}/V$. From Equation [59] for an altitude of $h = 300$ miles with $c_0 = 0.145 \times 10^{-9}$ and $V_0 = 17055$ mph, the angle β is about 1.23×10^{-6} radians. Consequently, the degree of eccentricity at problem initiation is extremely small.

The differential equations of motion from Equations [11] and [13] are then

$$\ddot{r} = r\omega^2 - \frac{a}{r^2} - c_0V_0r \qquad [60]$$

and

$$\dot{\omega} = \frac{2\dot{r}\omega}{r} - c_0V_0 \qquad [61]$$

with the initial conditions at $t = t_0$ and $r = r_0$ being

$$\omega_0 = \left(\frac{a}{r_0^3} + 2c_0^2V_0^2\right)^{1/2} \qquad [62]$$

$$\dot{r}_0 = -2c_0V_0r_0 \qquad [63]$$

and

$$\omega_0 \cong \frac{r_0^2}{r^2} e^{-c_0V_0(t-t_0)} \qquad [64]$$

The time interval, $\Delta t = t - t_0$, can be determined directly from Equation [64] for an arbitrary altitude loss, Δr, based on an average value for c and using the first two terms of the series expansion of the exponential term as follows: Since

$$e^{-2c_0V_0(t-t_0)} \cong 1 - 2c_0V_0(t - t_0) \qquad [65]$$

$$r \cong r_0[1 - 2c_0V_0(t - t_0)] \qquad [66]$$

The time interval for a loss in altitude of $\Delta r = r_0 - r$ is then

$$\Delta t = t - t_0 = \frac{r_0 - r}{2c_0V_0r_0} \qquad [67]$$

For the second interval, having determined r_1 and t_1, the differential equations of motion are then

$$\ddot{r} = r\omega^2 - \frac{a}{r^2} - c_1V_1r \qquad [68]$$

and

$$\dot{\omega} = -\frac{2\dot{r}\omega}{r} - c_1V_1 \qquad [69]$$

with the initial conditions at $t = t_1$ and $r = r_1$ being

$$\omega_1 = \left(\frac{a}{r^3} + 2c_1^2V_1^2\right)^{1/2} \qquad [70]$$

$$\dot{r}_1 = -2c_1V_1r_1 \qquad [71]$$

$$V_1 = (\dot{r}_1^2 + r_1^2\omega_1^2)^{1/2} \qquad [72]$$

Equations [70] and [71] in the first and second interval then involve three equations with three unknowns. By squaring and solving simultaneously, or by determinants, three independent equations for ω_1, $\dot{r}_1$ and V_1 in terms of constants and r_1 are obtained. These are

$$\omega_1 = \left[k_1 \frac{a}{r_1^3}(1 - 4c_1^2 r_1^2)\right]^{1/2} \qquad [73]$$

$$\dot{r}_1 = -2(k_1 a c_1^2 r_1)^{1/2} \qquad [74]$$

and

$$V_1 = \left(\frac{k_1 a}{r_1}\right)^{1/2} \qquad [75]$$

where

$$k_1 = \frac{1}{1 - 6c_1^2 r_1^2}$$

The solution for Equation [68] is then approximately

$$r \cong r_1 e^{-2c_1}\left(\frac{k_1 a}{r_1}\right)^{1/2}(t - t_1) \qquad [76]$$

and for small values of r

$$\Delta t = t - t_1 = \frac{r_1 - r}{2c_1 r_1 \left(\frac{k_1 a}{r_1}\right)^{1/2}} \qquad [77]$$

A simple approximation of Equation [77] is obtained by noting that since $k_1 = 1/(1 - 6c_1^2 r_1^2)$ and for the altitude of interest of about 4000 miles, $6c_1^2 r_1^2$ is extremely small with $k_1 \cong 1$. Equation [77] becomes

$$\Delta t = t - t_1 = \frac{r_1 - r}{2c_1 r_1 \left(\frac{a}{r_1}\right)^{1/2}} \qquad [78]$$

From the circularity equations, where $v^2 = g_0 R_0^2/r = a/r$, the time interval Δt_n for any arbitrary altitude loss $r_n = r_0 - r_1$ is

$$\Delta t_n = t_1 - t_0 = \frac{r_0 - r_1}{2cr_0 V_0} \qquad [79]$$

where the subscript n denotes the interval considered and 0 and 1 the initial and final values for r, V, and t. The average value of c is used throughout the interval. The total lifetime, t_L, from initiation of near-circularity to the surface is then the summation of the Δt's. Equation [79] is shown plotted in Fig. 9 for the special case of a sphere or cone having a drag coefficient $C_d = 2$, (diffuse reflection) cross-sectional surface area $s = 1$ ft² and mass of 1 slug based on the Grimminger atmospheric density data (7) and the Geophysical data (8) extrapolated to altitudes above 100 miles. Since the constant, c, involves the mass-to-area ratio m/a, this is used to indicate the effect of bodies having a large value of kinetic energy at initiation with respect to the existing drag energy. The solid-line curve shows expected orbit lifetimes for a sphere or cone from altitudes of 100 miles to 400 miles. The lifetimes for sphere (5) having an m/a ratio of 0.1 to 10 slug/ft² varies markedly with altitude. At 100 miles the lifetime for $m/a = 1$, the lifetime, t_1, is considerably less than 1 day, whereas at 200 miles, t_L is nearly 100 days. At higher altitudes, i.e., 300 miles, t_L is estimated to be about 1000 days with near-permanent orbits existing above 500 miles. For large variations in m/a the satellite lifetime varies proportionately. In Fig. 9 this effect is shown for satellite bodies of m/a values of 10 slugs/ft² and 0.1 slugs/ft². Bodies having values of about 1.0 would apply to minimum instrumented probes such as those proposed by Singer (3), Stehling (26), Levitt (27), and others. The larger values of 10 would apply to bodies having large length-to-diameter ratios, large missiles, or manned vehicles. Pierce (6) has considered spheres with $m/a < 0.1$ for use as radiation reflectors for intercontinental communications. These are, however, assumed to be used at extreme altitudes on near-permanent orbits where negligible drag exists. The estimated lifetime for the MOUSE (3) ($m/a = 1.273$) is

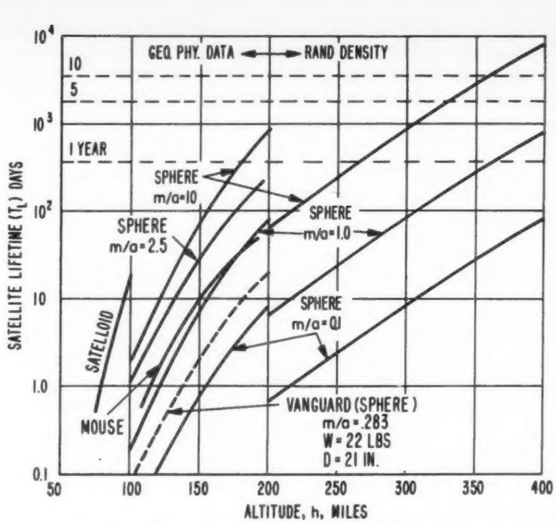

Fig. 9 Satellite lifetime vs. altitude for circular orbits (Refs.: Satelloid—Ehricke (5); Sphere m/a = 2.5 slug/ft²—Ehricke (5); MOUSE m/a = 1.273—Singer (3))

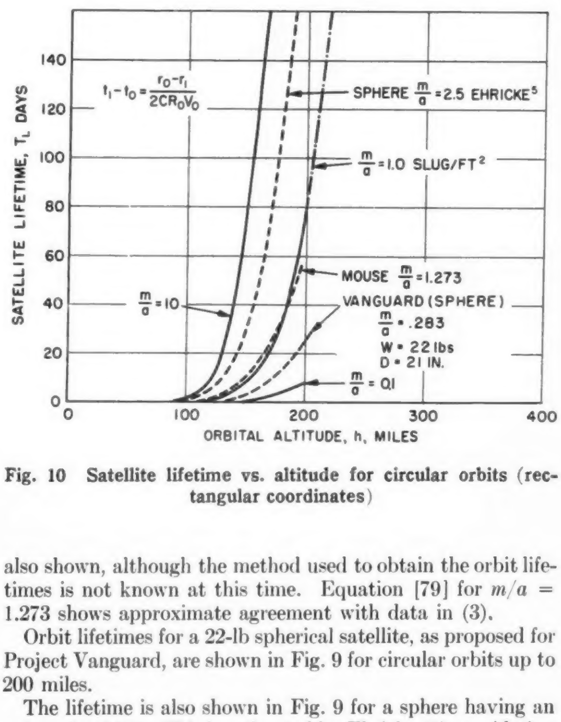

Fig. 10 Satellite lifetime vs. altitude for circular orbits (rectangular coordinates)

also shown, although the method used to obtain the orbit lifetimes is not known at this time. Equation [79] for $m/a = 1.273$ shows approximate agreement with data in (3).

Orbit lifetimes for a 22-lb spherical satellite, as proposed for Project Vanguard, are shown in Fig. 9 for circular orbits up to 200 miles.

The lifetime is also shown in Fig. 9 for a sphere having an m/a ratio of 2.5. This is estimated by Ehricke (5) considering a drag coefficient of 2.2.

Also illustrated for comparison is the curve for the powered satellite, the Satelloid (5), showing the lifetime vs. altitude for extremely low altitude orbiters. The Satelloid lifetime is increased simply by a sustained thrust force to overcome the high drag force at the low altitude. The expenditure of only 9 per cent of the payload extends the orbit lifetime significantly.

Fig. 10 shows an additional plot of the satellite lifetimes, on rectangular coordinates.

VI Characteristics of Elliptic Orbits

The space trajectory for a closed orbit about a central force field and neglecting atmospheric effects is defined by a conic

section, namely, the ellipse. Reference is made to Fig. 11 showing the two altitude extremes, perigee and apogee. Considering elliptic orbits the velocity along the flight path varies periodically between a minimum value (perigeal velocity) and a maximum value (apogeal velocity). At close proximity to the Earth's surface, perigee, the path velocity exceeds the circular velocity, whereas at the extreme altitude position, apogee, the velocity is less than that required for circularity at that altitude.

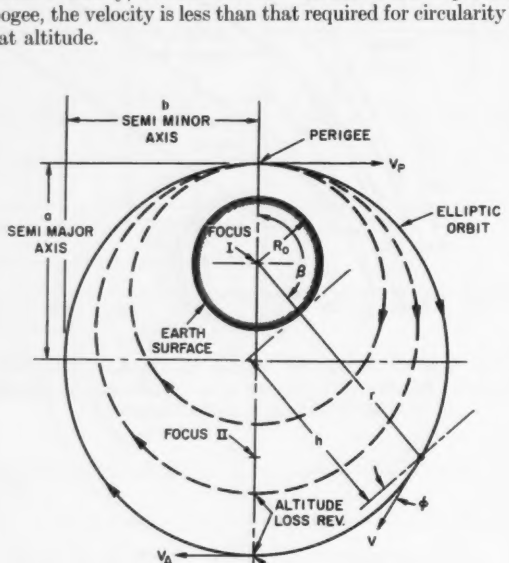

Fig. 11 Elliptic orbit characteristics

The equation's defining elliptic motion for a close orbit satellite are (*a*) polar equation of ellipse, (*b*) direction angle function, and (*c*) Kepler's third law of planetary motion. These are

(*a*) Elliptic polar equation

$$r_A = \frac{b^2/a}{1 + \frac{\sqrt{a^2 - b^2}}{a}\cos\beta_A} \quad\text{[80]}$$

(*b*) Direction angle:

$$\tan 2\phi_A = \left[\frac{2\sqrt{a^2 - b^2}\sin\beta_A}{r_A + 2\sqrt{a^2 - b^2}\cos\beta_A}\right] \quad\text{[81]}$$

(*c*) Kepler's third law of planetary motion:

$$V_1^2 = g_0 R_0^2\left(\frac{2}{r_A} - \frac{1}{a}\right) \quad\text{[82]}$$

where

r_A = orbit altitude above earth center
φ = directional angle (angle formed by tangent lines of orbit and earth's surface)
β_A = orientation angle

Equation [82] as illustrated in Fig. 12 shows the relationship between the perigee velocity and apogee altitude for a family of elliptic orbits having perigees of 100, 200, and 300 miles, with subsequent apogee altitudes varying up to 1000 miles. A constant perigee altitude, for example, $hp = 200$ miles, with cut-off or perigee velocities equal to or greater than that for circularity, $V_p > V_c$, results in elliptic orbits having apogees of increasing altitudes; that is, $h_A = h_{c_p}$. The required velocity increase at perigee V_p over circular velocity to attain an apogee 5 times that of perigee is not large. From Fig. 12 the circular velocity at a perigee of 200 miles is 17,250 mph. An increase of the perigee velocity to 18,000 mph will result in the attainment of 1000 miles at apogee. Thus a 4.35 per cent increase in cut-off velocity will greatly affect the ratio of h_A to h_p. However, the orbit eccentricity, e (ratio of minor to major axis) does not change appreciably. Thus the orbit shape remains nearly circular for these cases.

The determination of the elliptic orbit lifetime in this analysis is based on the assumption that the aerodynamic drag forces can be neglected at apogee while those near perigee simply result in a continual attenuation of the initial total orbital energy, existing at problem initation. Fig. 13 shows the total energy for a unit mass on an elliptic path about the Earth. For the 200 mile perigee the increase in kinetic energy to attain an apogee of 1000 miles is simple proportional to the velocity ratio of $(18{,}000/17{,}250)^2$. Thus a 9.3 per cent increase in energy is needed to attain this apogee of 1000 miles.

The drag forces exerted on a sphere for circular orbits is assumed, for a first approximation, to be applicable as well to elliptic orbits. Fig. 14 shows the sphere drag forces occurring for circular orbits based on density data from Grimminger (7) and LaGow (8). For the latter density data the estimated drag force at 100 miles altitude is 1000 times greater than that occurring at 235 miles. At 1000 miles the drag force is about 10^{-8} times as large as at 100 miles. Thus neglecting the apogee drag appears to be a valid assumption.

VII Determination of Elliptic Orbit Lifetimes

A precise analysis based on the true orbit perturbations caused by the drag forces cannot be readily calculated.

The orbital energy consumed by the atmosphere during one immersion near perigee is estimated to be

$$E_{d_p} = \left(c_d \frac{S\rho_p}{2} V_p^2\right) 2\pi a(R_0 + h_p) \quad\text{[83]}$$

where

E_{d_p} = drag energy for one rev at perigee
ρ_p = density at perigee
V_p = velocity at perigee
a = fraction of one revolution (1/2 is value assumed applicable) that sphere is exposed to atmospheric drag

Then

$$E_{d_p} = F_d\pi(R_0 + h_p) \quad\text{[84]}$$

The orbital energy at $t = 0$ is $E_{t_{0-1}}$ with the number of revolutions η to lose Δh miles in altitude is

$$\eta_{0-1} = \frac{E_{t_{0-1}}}{E_{d_p}} \quad\text{[85]}$$

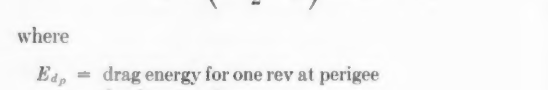

FIGURE 12
PERIGEE (BURNOUT) VELOCITY VS APOGEE ALTITUDE FOR ELLIPTIC ORBITS

Fig. 12 Perigee (burnout) velocity vs. apogee altitude for elliptic orbits

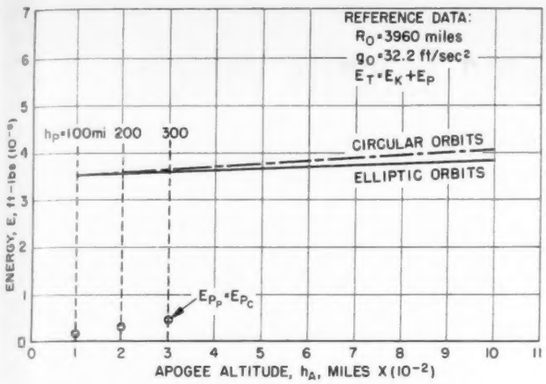

Fig. 13 Total energy of unit mass on elliptic orbits vs. apogee altitude

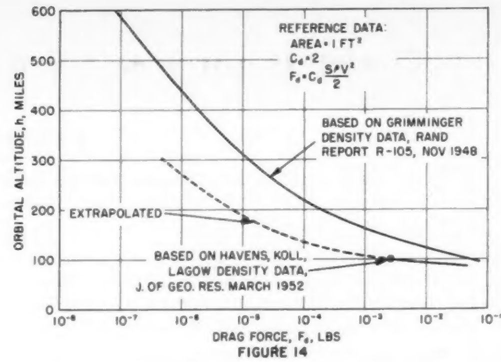

Fig. 14 Drag force on sphere for circular orbits

The lifetime is simply then

$$t_L = \eta_{0-1} + \eta_{1-2} + \ldots \ldots \ldots \ldots \quad [86]$$

The lifetime based on Equation [86] is only a very approximate estimate. The time to decay from the 1000 mile apogee altitude for the special cases having 100, 150, and 200 mile perigees are shown in Fig. 15. For $h_p = 200$ miles the satellite loses altitude at the rate of about 50 miles per year; at 150 miles the rate is 300 miles per year, and at 100 miles is 66 miles per day.

The characteristics for the MOUSE (3) showing the lifetimes for the low apogee altitude of 620 miles also appear in Fig. 15. These were estimated similarly by summing only the drag energy at perigee. The effect of increasing the apogee altitude from 620 miles to 1000 miles markedly increases the lifetime.

Table 1 below lists the lifetime data for both circular and elliptic orbits.

VIII Conclusions

The assumptions made in this paper permit only a "first approximation" answer to the orbit lifetimes. However, the actual densities at extreme altitudes are not known very precisely, and recent experimental tests indicate that the densities are even considerably less than those shown by LaGow (8) in 1952. This may permit the attainment of permanent orbits at much lower altitudes and give greater lifetimes to the first minimum satellites.

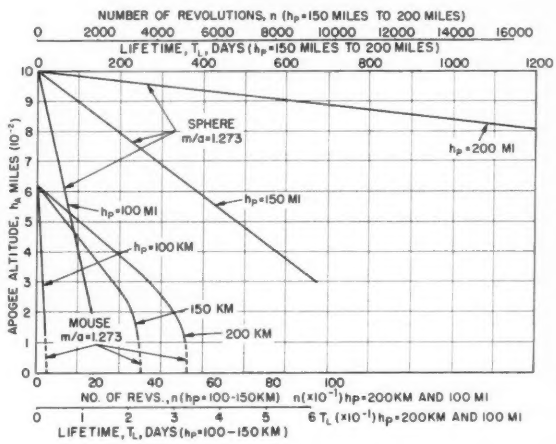

Fig. 15 Satellite lifetime from elliptic orbits

Table 1

Circular orbits

Body	m/a	h_c miles	t_L days
Sphere	0.01	200	8
Sphere	1	200	80
Sphere	10	200	800
MOUSE (3)	1.273	190	47
Sphere (5)	2.5	196	220
Satelloid (5)	11	100	18

Elliptic orbits

Body	m/a	h_p miles	h_A miles	t_L or rate
Sphere	1.273	100	1000	66 mi/day
Sphere	1.273	150	1000	300 mi/year
Sphere	1.273	200	1000	50 mi/year
MOUSE	1.273	62	621	0.2 days
MOUSE	1.273	93	621	2.25 days
MOUSE	1.273	124	621	33.0 days

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(Continued on page 368)

Flight Mechanics of Ascending Satellite Vehicles

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The types of satellite orbits and types of ascending trajectories to achieve these orbits are discussed. Both analog and digital computor techniques for trajectory computations are briefly described. A solution of the optimum vacuum stage thrust axis pitch program is presented for a satellite using continuous thrust all the way from ground to orbit. The procedure is explained for optimizing the trajectory to minimize propellant consumption for a vehicle using a power-off coast up to the orbit.

Nomenclature

D = drag
g = gravity acceleration = μ/r^2
I = specific thrust = thrust/propellant flow rate
R = range measured along surface of earth
R_A = distance from sun to target planet
R_P = distance from sun to earth
r = distance from center of earth or sun to vehicle
r_0 = earth's radius
T = thrust
t = time
t' = fractional second stage burning time
V = velocity
W = weight
Y = altitude
μ = universal gravity constant
α = angle of attack
β = depression angle of reference axis below burnout horizontal
γ = flight path angle
δ = rocket deflection angle
θ = pitch angle above local horizontal
θ_0 = initial second stage pitch angle above reference axis
φ = range angle = R/r_0
ψ = second stage pitch angle measured above launcher horizontal

Subscripts

A = apogee or aphelion
BO = burnout
C = circular
E = earth
MIN = minimum
P = perigee or perihelion
S = satellite, staging or sun
ST = starting
T = due to thrust
0 = at surface of earth
2 = second stage

1 Introduction

THE development of the concepts of space travel (1, 2),[2] the need for greater knowledge of the upper atmosphere, and the desire for military reconnaisance have created a present need for the construction and development of man-made satellites. The necessity of keeping the cost and propellant requirements to a minimum for placing a vehicle in a satellite orbit has spurred efforts to optimize the flight mechanics of ascending satellite vehicles. This paper covers some phases of the optimization of low altitude continuous thrust trajectories and high altitude interrupted thrust trajectories.

2 Types of Satellite Orbits[3]

Satellite orbits which involve human activity in space might be classified as permanent or temporary. Permanent orbits are those in which the satellites will remain in flight for more than 10 years before the aerodynamic drag will cause them to spiral down toward the earth. These orbits will probably be at altitudes in excess of 400 nautical miles and will be used for observational purposes. Temporary satellite orbits might be subdivided into:

1. Auxiliary orbits.
2. Orbits of departure for astronautical expeditions.
3. Orbits of arrival for astronautical expeditions.

Auxiliary orbits will be at altitudes of 120 to 150 nautical miles and will be occupied for only a few hours. Their purpose will be the transfer of payload from terrestrial supply ships to space ferries which carry the payload on out to the satellite orbit.

Orbits of departure of astronautical expeditions will propably be at altitudes between 350 and 400 nautical miles. These orbits will be occupied for durations of about one year for the purpose of assembling interorbital vehicles.

Orbits of arrival for astronautical expeditions for Mars and Venus will be 30,000 to 40,000 nautical miles from the earth. The duration of occupation of these orbits will be for a few days until passengers and cargo can be transferred to vehicles from the earth. These orbits will not be occupied by any permanent satellites or space stations.

The optimum orbits of departure are as close to the earth as possible; just outside of the atmosphere. Altitudes for orbits of arrival and orbits at other planets vary with the target planet.

3 Steps in Development of Interplanetary Flight[3]

Steps in the development of interplanetary flight are in chronological order:

1. Unmanned satellite.
2. Manned orbital glider (satellite rocket plane).
3. Permanent space station.
4. Space ships.
5. Interplanetary flight.

The first steps therefore in interplanetary travel are the development of manned and unmanned satellites.

4 Types of Ascending Trajectories

The subject of this paper deals with transferring the vehicle from the ground to the orbit in the most economical manner. That is to say, with the minimum expenditure of propellant and structural weight. For purposes of flight mechanics, powered flight trajectories could be classified according to the number of stages. At the end of each stage

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[2] Numbers in parentheses indicate References at end of paper.

[3] Sections 2 and 3 and the parts of Section 5 which relate to Figs. 1, 2, and 3 are obtained from Ref. (1).

of powered flight some components of the vehicle such as tankage and motors are jettisoned to avoid expending propellant to accelerate and lift these parts after they have served their purpose.

Ascending satellite trajectories might also be classified according to flight mechanics as follows:

1. Continuous thrust type.
2. Interrupted thrust type.

The continuous thrust type utilizes thrust in several successive stages all the way from the earth until the satellite orbit is attained. This type of ascent will usually be limited to low altitude orbits such as the auxiliary orbits already mentioned and orbits for instrumented meteorological observational satellites. This latter type of satellite has received widespread newspaper publicity recently. The interrupted thrust ascent will consist of two or three consecutive stages of powered flight followed by a power-off coast up to an elliptic apogee at the orbital altitude. At this point the thrust is resumed to accelerate the vehicle to the velocity required to maintain it in its circular satellite orbit. This interrupted thrust type of ascent will be used for most satellite trajectories.

5 Optimum Satellite Orbits[3]

Before entering into the details of trajectory calculations let us consider some general energy relations. The velocity required to go from one planet to another is the sum of the velocity to escape the home planet's residual gravitational field plus the velocity required to overcome the difference in potential energy of the solar gravitational field between the two planets. Referring to Fig. 1, the curve represents the solar field and superimposed planetary gravity fields as equivalent parabolic velocity with respect to the sun versus distance from the sun. The difference in the square of the velocities between any two points on this curve is proportional to the energy required to overcome the sun's attraction in moving from one to another. The velocities required to overcome the planets' gravitational fields are shown as V-shaped pockets at each planet location.

The velocity required to leave a satellite orbit about the earth and proceed to another planet depends upon the radius of the satellite orbit. The larger the satellite orbit, the weaker is the gravitational attraction of the home planet. This has a tendency to *reduce* the velocity required to go to another planet. On the other hand the larger the satellite orbit the lower is the circular velocity of an object in that orbit. This has a tendency to *increase* the additional velocity required. Therefore there is an optimum satellite orbit of departure (or arrival) to go from each planet to each other planet. It will be shown that at this optimum distance of departure (or arrival) the energy of the residual planetary gravity field must equal the difference in potential energy of the solar gravity field between the two planets contacted. These energy requirements are shown in Fig. 1 as $\Delta E_{\oplus}$ and $\Delta E_{\odot}$ for the earth's and sun's gravitational fields, respectively, for an earth-to-Mars expedition.

Consider a vehicle moving in unpowered flight in a Keplerian elliptic orbit and subject to the gravity attraction of *only* one planet or sun at a focus of that orbit. Since after power cutoff no external forces act upon the vehicle, the sum of its kinetic and potential energy is constant. This is expressed in Equation [1] where the first term is proportional to the kinetic energy and the second term proportional to the potential energy.

$$V^2 - \frac{2\mu}{r} = \text{const} \qquad [1]$$

The moment of momentum is likewise constant and is expressed at the perigee and apogee by Equation [2].

$$Vr = \text{const} \qquad [2]$$

Equations [1] and [2] are combined in Equation [3] to express the perigee velocity in terms of the perigee and apogee radii and the gravitational constant of the focus planet.

$$V_P = \sqrt{\frac{2\mu}{r_P[1 + (r_P/r_A)]}} \qquad [3]$$

This perigee velocity is the minimum velocity required to enter the transfer ellipse from the satellite orbit to the target planet.

In the case of the earth the perigee distance would be the satellite orbital distance from the center of the earth and the apogee distance would be from the center of the earth to the target planet. The ratio r_P/r_A would be so close to zero as to be negligible. Equation [3] would then simplify to Equation [4] which is the parabolic escape velocity from the earth.

$$V = \sqrt{\frac{2\mu_E}{r_S}} \qquad [4]$$

where r_S is $r_0 + Y$.

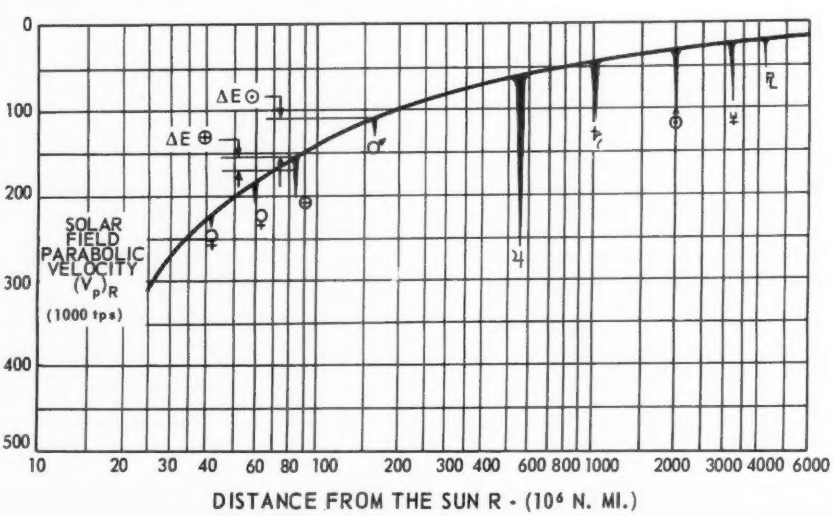


Fig. 1 Gravity field of sun and planets

In the case of the sun being the only force acting upon the satellite vehicle, the perihelion distance would be the distance from the center of the sun to the satellite as it leaves its orbit to enter the transfer ellipse. For practical purposes this is the distance from the sun to the home planet's (earth) orbit. The aphelion distance is the distance from the sun to the orbit of the target planet. Equation [3] for a satellite acted upon by the sun only then becomes

$$V = \sqrt{\frac{2\,\mu_S}{R_P[1 + (R_P/R_A)]}} \quad \text{[5]}$$

The velocity of Equation (5) is with respect to the sun. If this velocity is measured relative to the earth which is traveling about the sun at orbital speed, Equation [5] becomes

$$V = \sqrt{\frac{2\,\mu_S}{R_P[1 + (R_P/R_A]}} - \sqrt{\frac{\mu_S}{R_P}}$$

$$= \sqrt{\frac{\mu_S}{R_P}}\left[\sqrt{\frac{2}{1 + (R_P/R_A)}} - 1\right] \quad \text{[6]}$$

Equations [4] and [6] represent the minimum or elliptic perigee velocities (with respect to the earth) required for an earth satellite to leave its orbit and move out to a target planet when subject to only the gravitational effect of the earth and of the sun, respectively. The energy which the vehicle must possess as it enters the transfer ellipse must be the sum of the energy required to overcome the gravitational fields of the earth and of the sun. Since kinetic energy is proportional to the square of velocity, the velocity required is the square root of the sum of the squares of the velocities of Equations [4] and [6]. Therefore, the additional velocity required to bring the vehicle from its initial circular satellite orbital velocity up to the starting velocity to enter the transfer ellipse is presented in Equation [7].

$$\Delta V_{ST} = \sqrt{\frac{2\,\mu_E}{r_S} + \frac{\mu_S}{R_P}\left[\sqrt{\frac{2}{1 + (R_P/R_A)}} - 1\right]^2} - \sqrt{\frac{\mu_E}{r_S}} \quad \text{[7]}$$

Setting the differential of this expression with respect to r_S equal to zero results in Equation [8] which shows that for the minimum incremental velocity ΔV_{ST} the individual energies required to overcome the earth's and the sun's gravitational fields are equal. Of course their respective velocities, Equations [4] and [6], are also equal.

$$\frac{2\,\mu_E}{r_S} = \frac{\mu_S}{R_P}\left[\sqrt{\frac{2}{1 + (R_P/R_A)}} - 1\right]^2 \quad \text{[8]}$$

The optimum orbital distance is seen from Equation [8] to be

$$r_S = \frac{2\,\mu_E R_P}{\mu_S\left[\sqrt{\frac{2}{1 + (R_P/R_A)}} - 1\right]^2} \quad \text{[9]}$$

The optimum orbital distance is plotted in Fig. 2 as a function of the distance from the sun. These results apply only to the change in velocity required for departure or arrival by means of one impulse only (3, 4). It will be noted that there is an asymptote at eighty million nautical miles, the location of the earth. The closer the target planets are to the earth, the greater the optimum satellite orbital distances and vice versa. For Mars and Venus, the only two planets likely to be contacted in the near future, the orbital distance is of the order of 50,000 nautical miles. For trans-Uranian planets the optimum orbit lies mathematically within the earth, which means practically just outside of the earth's atmosphere.

These orbital distances (Fig. 2) are optimum only from the standpoint of earth-target planet transfer. When the assembly of the interplanetary expedition in the orbit of departure is considered we see a different picture. Everything in the satellite orbit must be transported there from the earth at a considerable expenditure of energy.

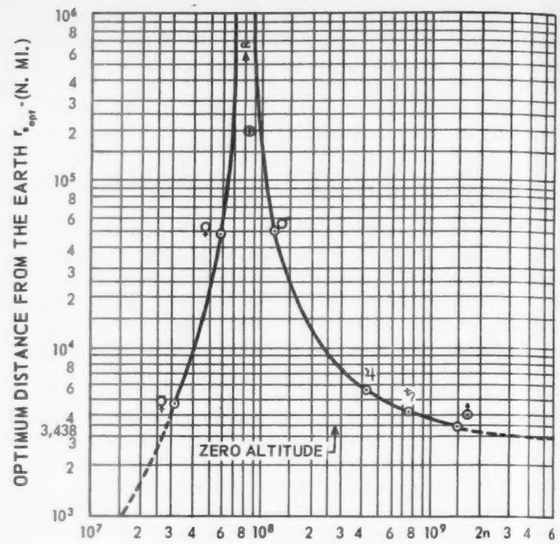


Fig. 2 Optimum distance of departure or arrival as function of the target planet

Various components of velocity required for a Mars expedition are presented in Fig. 3 as a function of orbital distance from the center of the earth. It is assumed that the vehicle starts from local circular velocity in an auxiliary orbit just outside of the earth's atmosphere. A component of thrust velocity ΔV_{II} must be added to the circular velocity V_c to put the vehicle into a transfer ellipse to the main satellite orbit. The vehicle arrives in the satellite orbit at its apogee velocity V_A. An additional component of velocity ΔV_{III} must now be added to achieve circular orbital velocity. To acquire starting velocity to proceed from the satellite orbit into outer space the final increment of thrust velocity ΔV_{ST} is now applied. The sum of the three components of velocity ΔV_{II}, ΔV_{III}, and ΔV_{ST} is the total thrust velocity required to go from the auxiliary orbit just outside of the earth's atmosphere to the target planet. The optimum orbit of departure, where the sum of these velocities is a minimum, is seen from Fig. 3

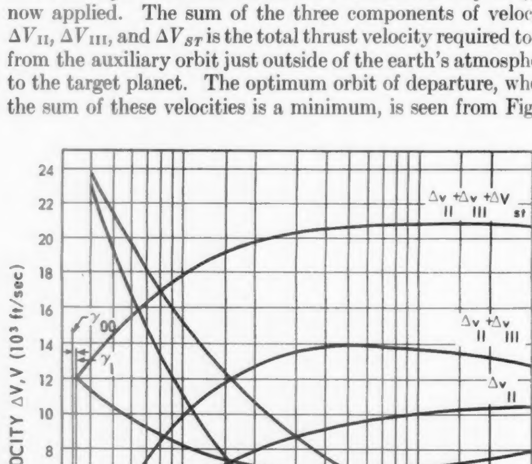


Fig. 3 Effect of supply system on selection of assembly orbit of interplanetary expedition to Mars

to be as close to the earth as possible. Fig. 3 is for a Mars expedition, but the same conclusion would apply to other planets as well.

The orbital distances of Fig. 2 apply fairly well to orbits of arrival of astronautical expeditions. However, it may be seen in Fig. 3 that the orbital distance may be reduced somewhat below that for minimum ΔV_{ST} without any appreciable increase in this thrust velocity increment. Reducing this orbital distance would therefore require the space ship to carry very little more propellant to decelerate it into the orbit of arrival, but a smaller orbit would greatly reduce the supply problem from that orbit. Therefore the optimum orbits of return for Venus and Mars expeditions will be between altitudes of 30,000 and 40,000 nautical miles.

We have discussed orbits of departure and arrival of interplanetary travel. Let us now consider the minimum energy requirements to achieve a low altitude orbit. This velocity is presented in the first equation of Fig. 4, Equation [10]. The radicals were removed from these equations on the assumption that the ratios of the altitude to the radius of the earth was very small.

This minimum thrust velocity is composed of two components; the velocity required to transfer the vehicle from the surface of the earth to the satellite orbit and the velocity required to achieve circular orbital velocity to maintain that orbit. It was assumed that the vehicle was launched horizontally from the surface of the earth, in the absence of

$$(10)\quad V_{T_{MIN}} = \sqrt{\frac{\mu}{r_S}\left(1+\frac{2Y_S}{r_0}\right)}$$

$$(11)\quad = V_C\sqrt{1+\frac{2Y_S}{r_0}} = V_C\left(1+\frac{Y_S}{r_0}\right)$$

$$(12)\quad = V_{C_0}\sqrt{1+\frac{Y_S}{r_0}} = V_{C_0}\left(1+\frac{1}{2}\frac{Y_S}{r_0}\right)$$

$$(13)\quad = 26{,}000\left(1+\frac{1}{2}\frac{Y_S}{r_0}\right)$$

Fig. 4 Minimum thrust velocity for low altitude orbit

atmosphere and by means of an instantaneous impulse. Practical considerations require a vertical launching and a finite burning time. These factors cause a greater gravity loss than is included in Fig. 4. This, together with final thrust velocity lost due to changing thrust direction, amounts to about 6300 ft/sec. Aerodynamic drag accounts for about 350 ft/sec and steering losses (due to rocket jet deflections) for as much as 50 ft/sec. These losses when added to the theoretical minimum velocity require an ideal thrust velocity of 32,000 ft/sec to achieve a 175 n. mi. orbit with orbital speed. This ideal thrust velocity, when taken into account with design considerations, could be used to determine the approximate size of the vehicle without the necessity of trajectory computations.

6 Trajectory Machine Computations

Trajectory calculations are made on either an analog or digital computing machine. The analog machine has the advantage of enabling the operator to run a few trajectories, examine the results, and by trial and error make on-the-spot changes to optimize the trajectory. The analog computer, however, has the disadvantage of being too inaccurate for most trajectory work.

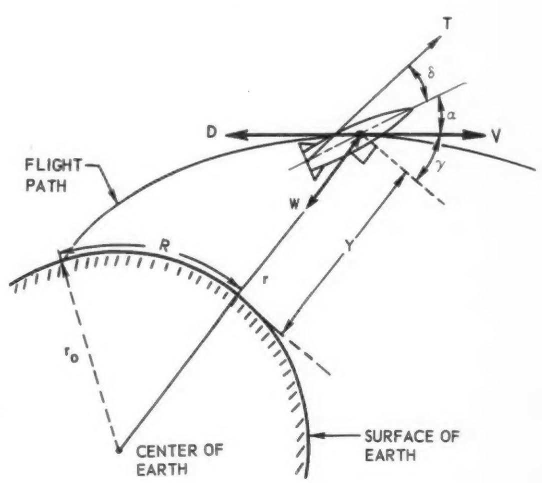
Digital computers of either the card program calculator (CPC) or high speed types are used for trajectory computations. CPC machines are relatively slow requiring as much as an hour and a half to compute a single trajectory. The practical time for the high speed machine is the printing time since the actual computation is very rapid. The Sperry-Rand 1103 High Speed Digital Computer is typical of these machines. It has three storage capacities. The high speed electrostatic storage contains 36 cathode tubes, each with a grid 32 by 32, thus giving a storage capacity of 1024 words of 36 binary bits each. The magnetic drum storage has a capacity of 16,384 words. Entire blocks of data are transferred from the magnetic drum to the high speed storage as needed. The drum is addressable which gives the machine an advantage over others of its type. The third storage, a magnetic tape, has an unlimited capacity because more tape may be added. Access time for the high speed electrostatic storage is of the order of 6 to 8 microsec while that of the slower drum is 4 millisec. One thousand words per second may be read from the magnetic tape.

The symbols and equations used in machine trajectory computations are presented in Fig. 5, Equations [14], [15], and [16].

The last term in Equation [15] is the rate of change of the direction of local horizontal with time. This term is present because the flight path angle is measured above local horizontal rather than from a fixed reference.

The thrust in the equations of Fig. 5 is supplied as a function of altitude because, even for constant flow rate rockets, the thrust varies with the ambient pressure acting on the base of the rocket. Weight is obtained from the integration of the propellant flow rate which might also be a function of altitude. Drag and lift are functions of speed, altitude, and angle of attack. The angle of attack may be specified as a function of time or the machine may compute the angle of attack from a predetermined pitch-time program. The rocket deflection angle δ is obtained by balancing the aerodynamic pitching moment by a thrust moment about the vehicle's center of gravity.

The basic trajectory data, thrust, and drag, etc., is fed to the machine in either equation form or tables. In the case of tables, discreet points are read into the machine not necessarily at equal intervals. The machine then passes a polynomial curve through several successive points to determine the values between the points.



$$(14)\quad \frac{dV}{dt} = \left(\frac{T\cos(\alpha+\delta) - D}{W}\right) g_o - \frac{\mu}{r^2}\sin\gamma$$

$$(15)\quad \frac{d\gamma}{dt} = \frac{1}{V}\left[\left(\frac{L + T\sin(\alpha+\delta)}{W}\right) g_o - \frac{\mu}{r^2}\cos\gamma\right] + \frac{V\cos\gamma}{r}$$

$$(16)\quad \frac{dr}{dt} = V\sin\gamma$$

Fig. 5 Symbols of powered flight trajectories

Integration of the trajectory equations is generally carried out using time as the independent variable in small increments. Several methods of approximation, including the following three, may be used for integration.

1. Taylor series.
2. Runge-Kutta.
3. Predictor-corrector.

In the predictor-corrector method the values of V, γ, r, and R and their first derivatives at two successive points are used to predict the value of these functions at the next point at the end of the next time interval. The new values are next applied to Equations [14], [15] and [16] of Fig. 5 to find their first derivatives, which in turn are used to correct the predicted values. This procedure may be iterated until the error becomes less than a predetermined permissible limit, or, if the error is larger than the acceptable limit, the time interval may be automatically reduced.

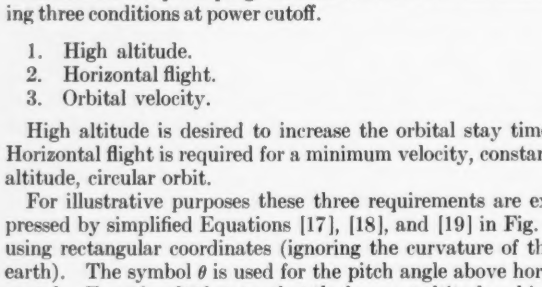
7 Optimum Vacuum Stage Pitch Program for Low Altitude Satellite

A sketch of a low altitude continuous thrust ascent trajectory is presented in Fig. 6. The vehicle is launched vertically into a zero-lift gravity turn terminating at the staging point outside of the atmosphere. At staging, some components of the vehicle such as propellant tankage and motors are jettisoned. Second-stage powered flight is accomplished by the remaining rocket engines using a pitch-time program. This is to say, the orientation of the thrust axis of the vehicle is varied as a predetermined function of time. The problem is to determine the pitch program that will result in the following three conditions at power cutoff.

1. High altitude.
2. Horizontal flight.
3. Orbital velocity.

High altitude is desired to increase the orbital stay time. Horizontal flight is required for a minimum velocity, constant altitude, circular orbit.

For illustrative purposes these three requirements are expressed by simplified Equations [17], [18], and [19] in Fig. 6 using rectangular coordinates (ignoring the curvature of the earth). The symbol θ is used for the pitch angle above horizontal. Equation [17] states that the burnout altitude, which is the sum of the known staging altitude, the altitude gained due to staging velocity, the altitude gained due to second stage thrust and the altitude lost due to gravity, must be a maximum, consistent with the other two conditions. Equation [18] satisfies the requirement of horizontal flight at power cutoff. It states that the sum of the vertical components of velocities at staging, contributed by vacuum stage thrust and by gravity in the vacuum stage is zero. The third equation, Equation [19], states that the sum of the horizontal component of velocity at staging and the horizontal velocity contributed by second-stage thrust is equal to circular orbital velocity at burnout. It may be noted that the burnout altitude term Y_{BO}, occurring in Equation [19] is the same function occurring in Equation [17].



SIMPLIFIED EQUATIONS

$$(17)\quad Y_{BO} = Y_S + t_2 V_S \sin\gamma_S + g_0 \int_{t_1}^{t_2}\int_{t_1}^{t} \frac{T}{W}\sin\theta\, dt\, dt - \int_{t_1}^{t_2}\int_{t_1}^{t} \frac{\mu}{(r_0+Y)^2}\, dt\, dt = \text{MAX}$$

$$(18)\quad V_S \sin\gamma_S + g_0 \int_{t_1}^{t_2} \frac{T}{W}\sin\theta\, dt - \int_{t_1}^{t_2} \frac{\mu}{(r_0+Y)^2}\, dt = 0$$

$$(19)\quad V_S \cos\gamma_S + g_0 \int_{t_1}^{t_2} \frac{T}{W}\cos\theta\, dt = \sqrt{\frac{\mu}{r_0 + Y_{BO}}}$$

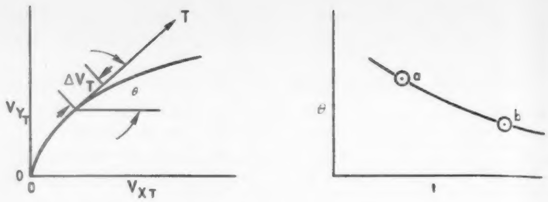
Fig. 6 Satellite powered all the way to orbit

The object is now to find θ as a function of time which will atisfy these three equations simultaneously. One procedure would be to integrate the equations of Fig. 6, using an assumed form for the equation $\theta = f(t)$ and thus determine the optimum coefficients for the equation. This procedure is so laborious that it limits the selection of possible forms. It has an even more severe disadvantage in that, although it results in the optimum equation of the selected form, there is no assurance that a much better form does not exist.

The fundamental principle for deriving the method of optimizing the vacuum stage pitch program used herein is best illustrated by assuming a simple X, Y rectangular coordinate system. Only the contribution of thrust to velocity need be considered because the staging velocity is known and the second-stage gravity velocity is closely approximated by the product of the second-stage burning time and an assumed average gravity constant.

Let us now assume that we wish to acquire a maximum vertical distance and achieve a definite horizontal velocity at power cutoff, but we do not require the vertical velocity at power cutoff to be zero. In other words, we do not stipulate horizontal flight at burnout.

Vertical thrust velocity is plotted against horizontal thrust velocity in Fig. 7. The thrust, of course, acts tangent to this curve. Also shown is the small increment in thrust velocity, ΔV_T, acquired over the small time increment Δt.



$$(20)\quad \Delta V_X = \Delta V_T \cos\theta$$

$$(21)\quad \Delta Y_B = (t_B - t)\,\Delta V_T \sin\theta$$

$$(22)\quad d\Delta V_X = -\Delta V_T \sin\theta\, d\theta$$

$$(23)\quad d\Delta Y_B = (t_B - t)\,\Delta V_T \cos\theta\, d\theta$$

$$(24)\quad \sin\theta_a\, d\theta_a = -\sin\theta_b\, d\theta_b$$

$$(25)\quad (t_B - t_a)\cos\theta_a\, d\theta_a = -(t_B - t_b)\cos\theta_b\, d\theta_b$$

$$(26)\quad \boxed{\tan\theta = \tan\theta_0\,(1 - t')}$$

Fig. 7

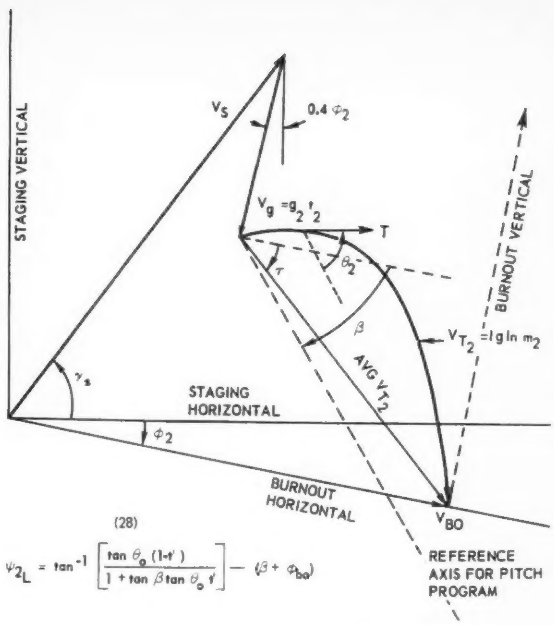
To obtain a solution let us first assume that the curve of θ as a function of t shown in Fig. 7 is the optimum and that "a" and "b" are general points on this curve. The increment of horizontal velocity gained over a small time increment at any point on this curve is given in Equation [20] of Fig. 7. The contribution to burnout vertical distance over the same time increment is shown in Equation [21] to be the incremental vertical velocity acting over the remainder of the burning time. Small changes in the ΔV_x and ΔY_B increments caused by small changes in the pitch angle are obtained by differentiating Equations [20] and [21] to give [22] and [23], respectively.

To this point the derivation has been perfectly general. We now stipulate that a definite horizontal component of velocity must be achieved at power cutoff. This may be accomplished by adjusting the small changes in pitch angle at points "a" and "b" so that there is no net change in V_x. This is done by equating the sum of Equation [22] at points "a" and "b" to zero to yield Equation [24]. These changes in θ at "a" and "b" must cause no net change in Y_B. Obviously $d\theta_a$ and $d\theta_b$ must be opposite in sign and either one can be positive and still satisfy Equation [24]. Therefore burnout altitude will be gained at one point "a" or "b" and lost at the other. If the increase in burnout altitude due to an infinitesimal change in θ at one point is greater than the loss at the other point, these changes should be put into effect, since they result in a gain in altitude without any loss of horizontal velocity. If a change in the function θ is warranted, we do not have the optimum curve. This would be contrary to our original optimistic assumption. Therefore, the sum of the value of Equation [23] at points "a" and "b" may be equated to zero to yield Equation [25].

Equation [24] satisfied the condition of a definite burnout horizontal velocity (orbital speed) and Equation [25] satisfies the requirement of maximum burnout altitude consistent with Equation [24]. Dividing Equation [24] by Equation [25] results in the final expression for pitch angle program, Equation [26] where θ_0 is the initial pitch angle at the start of second stage flight and t' is the fractional second stage buring time (initially 0, finally 1.0). This equation simply states that the tangent of the pitch angle above the reference axis diminishes linearly with time to zero degrees to achieve the maximum distance moved normal to the reference axis with the minimum loss of velocity in the reference direction. The application of the principle of this equation may be explained with the aid of the velocity vector diagram of Fig. 8.

Staging horizontal and burnout horizontal differ in Fig. 8 by the second-stage range angle φ_2. This is the angle subtended at the center of the earth by the vehicle's staging and burnout locations. Staging velocity V_S and flight path angle γ_s (Fig. 8) are known. The gravity velocity of the second stage V_g is closely determined as the product of the known second stage burning time and an average gravitational constant. This gravity velocity initially acts parallel to the staging vertical and finally parallel to the burnout vertical. An average value of four tenths of this range angle difference was empirically arrived at as the result of numerous trajectory calculations. Burnout velocity V_{BO} must lie along the burnout horizontal. Its magnitude is fairly well determined in advance since we have a fair idea of the burnout altitude and consequently the circular orbital velocity for this altitude. We now know the staging velocity, the second stage gravity velocity and the required burnout velocity. All that remains is to determine the pitch program that will best connect the end of the V_g vector with the V_{BO} vector of Fig. 8.

The depression angle τ of the average second stage thrust direction, $AVG\ V_{T_2}$ (Fig. 8) is known. This angle is usually less than three degrees. If all of the second stage thrust were to be oriented in this average direction the desired burnout velocity would be achieved with the minimum expenditure of propellant. This, however, would result in an extremely low burnout altitude. Assuming there is more than this minimum



(28)

$$\psi_{2_L} = \tan^{-1}\left[\frac{\tan\theta_0\,(1-t')}{1+\tan\beta\tan\theta_0\,t'}\right] - (\beta + \varphi_{bo})$$

Fig. 8 Velocity vector diagram

propellant, we may vary the direction of the thrust as a function of time to form the curve labeled V_{T_2} in Fig. 8. The length of this curve is equal to the product of the specific thrust (ratio of thrust to fuel flow), the sea level gravity constant and the logarithm of the second stage mass ratio (ratio of weight just after staging to burnout weight). The thrust at any point acts tangent to this curve. If the average thrust direction were used as the reference axis in applying the pitch equation just derived, a component of velocity perpendicular to this direction would result, which would prevent horizontal burnout. This may be avoided by depressing the reference axis below the $AVG\ V_{T_2}$ direction and going through a derivation similar to the one just described. In this case we maximize the altitude, not at right angles to the reference axis, but parallel to the burnout vertical, to achieve maximum burnout altitude.

The final equation number (27), is presented in Fig. 8 where

Ψ_{2_L} = second stage pitch angle above launcher horizontal
β = depression angle of reference axis below burnout horizontal
θ_0 = initial second stage pitch angle above reference axis
φ_{BO} = burnout range angle measured from launching site
t' = fractional second stage time

The range angle, φ_{BO}, may be estimated in advance since the average second stage flight path angle is very low.

The unknown angles θ_0 and β in the equation of optimum pitch angle may be determined by either of the following two methods.

1. Mathematically integrate average thrust velocity using Equation [27] of Fig. 8 and plot θ_0 and β as functions of $AVE\ V_{T_2}$ and m_2. Using the $AVE\ V_{T_2}$ from the vector diagram, the values of θ_0 and β could be immediately obtained from the plot and used to calculate the optimum ascending satellite trajectory. A typical plot illustrative of this method of solution is presented in Fig. 9 for the specific case of a second stage loading factor of 0.865.

2. Assume a series of values for θ_0 and β and run a machine trajectory computation for each combination. The results could then be plotted and cross-plotted to determine the optimum.

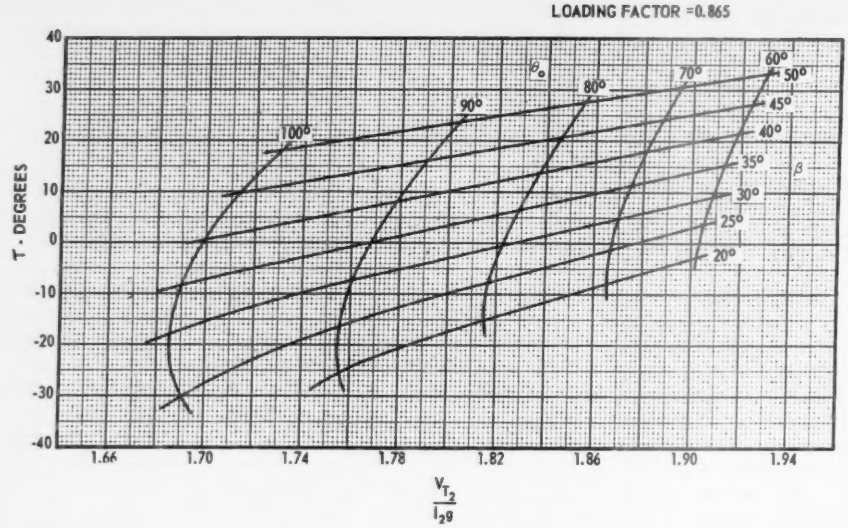


Fig. 9 τ vs. V_{T_2}/I_{2g} for various values of θ_0 and β

Both of these methods work fairly well. Except for the time of making up the plot of θ_0 and β versus $AVE\ V_{T_2}$ and m_2, the first method is faster but less accurate than the second method.

8 Interrupted Thrust Trajectory Optimization

We have discussed the flight mechanics of low altitude satellites using power all the way from launching to the satellite orbit. Let us now consider the interrupted thrust type of trajectory. A three-stage interrupted thrust trajectory is illustrated in Fig. 10. The first stage consists of a zero lift gravity turn commencing with a vertical launching at point 1 and terminating above the atmosphere at point 2. At this

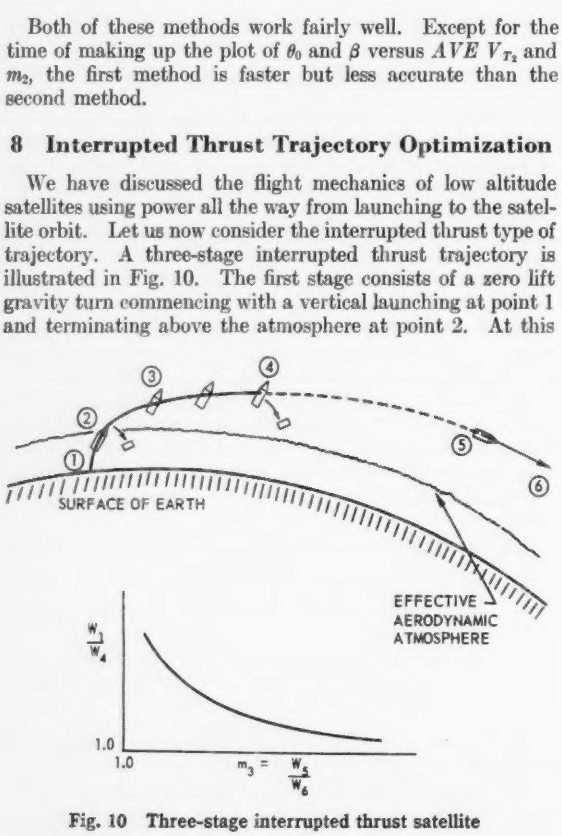


Fig. 10 Three-stage interrupted thrust satellite

staging point some of the missile tankage and motors are jettisoned. The second stage of powered flight from point 3 to 4 takes place above the atmosphere with the thrust axis oriented in one direction in space. This is done to gain the maximum velocity and hence the maximum kinetic energy at second stage power cutoff. The constant pitch angle trajectory is simple from the guidance standpoint and yields very close to optimum results. At point 4 additional tankage and motors are jettisoned and the third stage vehicle or powered nose section continues to rise without power to an elliptic apogee at point 5. At this point if power were not resumed the vehicle would fall back to earth, completing a typical long range ballistic trajectory. Thrust is resumed at or near the apogee, point 5, to accelerate the vehicle to local circular orbital velocity at point 6.

Actual trajectory calculations are made for the interrupted thrust type of ascent by using several trajectory variables as follows. The "tilt angle" or flight path angle at a definite point early in the first stage of powered flight determines whether the first stage trajectory is steep or relatively flat. The other three variables are the time of staging at point 2, the second stage pitch angle, and the time or vehicle weight at second stage power cutoff at point 4. These four variables determine the kinetic and potential energy and the flight path angle of the vehicle at second stage burnout. In turn, these burnout conditions determine the speed and altitude of the vehicle upon its arrival at the elliptic apogee point 5. The orbital altitude at point 5 determines the required circular velocity and the difference between this and the apogee velocity must be made up by the third stage thrust.

By computing a series of trajectories for any family of missiles using the four trajectory variables mentioned and then plotting and cross-plotting the results, a plot may be made similar to the one in Fig. 10. This plot presents the ratio of takeoff weight to weight at the end of the second stage as a function of the third stage mass ratio or ratio of weight at the beginning to weight at the end of the third stage.

As seen from the plot in Fig. 10, vehicles requiring a large combined first and second stage require only a small third stage, and vice versa. The weight ratios from this curve are valid for a variety of missiles of this type. Exact weights depend upon the weights jettisoned and upon the component weight estimates and safety factors used. Designers and weight men may use a plot of this type to determine the final design.

9 Conclusion

In conclusion it may be said that from general performance studies, coupled with preliminary weight estimates, we can determine an approximate optimum design or region of practical designs to accomplish any particular mission. The *exact design*, however, depends upon the ingenuity of the designer in saving weight, selecting materials, and fitting the various components into the allowable space.

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Satellite Ascent Mechanics

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THIS paper discusses that phase of satellite ascent mechanics concerned with the guidance accuracy requirements. Assuming a three-stage launch vehicle, one can obviously make a number of combinations of powered and coasting flights which will bring the satellite into a desired orbit. In the case of an all-powered trajectory, i.e., continuous burning until orbital altitude and velocity are reached, the guidance problem is essentially one of determining and controlling only the orbital injection conditions. The exact manner in which the orbit is reached is very important from the performance standpoint, but not so important as far as the guidance is concerned.

The result of an error in injection elevation angle, assuming the correct velocity magnitude, is to increase the apogee and decrease the perigee by about 65 nautical miles per degree of elevation angle error. The result of an error in injection velocity, assuming the correct injection angle of 0 degree, is to increase the apogee altitude or decrease the perigee altitude by 60 nautical miles per 100 feet per second velocity error, depending on whether the velocity is higher or lower than circular orbital velocity. With given allowable perigee and apogee altitudes one can, for a given injection point altitude, determine an allowable region inside which the velocity error and the elevation angle error must fall in order to restrain the satellite to move within the specified apogee and perigee bounds.

For example, it can be determined that with an orbital injection point at 300 nautical miles, a perigee limit of 200 nautical miles, and an apogee limit of 800 nautical miles, a velocity tolerance of about ± 1 per cent and an elevation angular tolerance of about ± 2.25 degrees will keep the satellite within the orbital limits.

The question of azimuth tolerance requires consideration of the geographical (or celestial) latitude of the orbital injection point. The error in the angle of inclination between the orbit plane and the earth's equatorial plane, which is the important quantity, is not equal to the error in the injection azimuth direction except if the satellite is injected at the equator. The angle of inclination (α) is related to the injection azimuth angle (β) (measured from the North) by $\cos \alpha = \cos a \cdot \sin \beta$, where a is the latitude of the injection point. One can readily compute the error in the angle of inclination resulting from an error in the injection azimuth. At an injection latitude of 28 degrees, an azimuth error of 6 degrees from a 90-degree firing (i.e., due East) will result in an error in the angle of inclination of about one-half degree. If the azimuth direction were 0 degree (i.e., due North), a 6-degree azimuth error would result in an error in the angle of inclination of about 5.3 degrees.

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If a coasting period between the second and third stages is introduced, the second stage after burnout will coast to an apogee at the desired orbital altitude. At this point the third stage is fired giving the satellite the boost required to establish an orbit. Under these conditions one can readily determine the conditions which will have to exist at the second-stage burnout to give satisfactory injection with any given third-stage performance. For any given second-stage altitude (h_0) there exists one set of values for burnout velocity (v_0) and burnout angle (γ_0) which gives the correct injection point altitude. In general it is desirable to pick values for h_0, v_0, and γ_0 resulting in conditions at the injection point which will require the least amount of third stage boost.

This reasoning leads one to go as fast as possible and as flat as possible (i.e., with a small γ_0), which is a condition with rather obvious restrictions considering first and second stage performance limitations. Starting with a second stage burnout at 800,000 feet with a γ_0 of 2 degrees, it takes a v_0 of about 25,500 feet per second to arrive at an injection point of 300 miles. At this time a 500 foot-per-second additional boost is required to get into a circular orbit. If, on the other hand, one starts out with a γ_0 of 12 degrees, it takes a v_0 of about 21,300 feet per second to arrive at the same injection point. In this case, the additional boost required from the third stage will be 5000 feet per second. To obtain the same injection point conditions starting from an initial altitude of 250,000 feet, a v_0 of 25,900 feet per second and 22,300 feet per second, respectively, and a slightly larger γ_0 than required for the higher burnout altitude will be required.

The error in the injection altitude is about 25 miles per degree of error in burnout angle. There is also an injection altitude error of about 43 miles per 100 feet per second of burnout velocity error at a γ_0 of 2 degrees. This error drops to about 6 miles per 100 feet per second velocity error at a γ_0 of 14 degrees.

One interesting effect of these errors in the orbital conditions is the change in the period of revolution (T) of the satellite. For a nominal altitude of a few hundred miles, the change in T due to an initial altitude error of 1000 feet is about 0.4 seconds, assuming all other conditions to be correct. The change in T due to an initial velocity error of 100 feet per second is about 70 seconds. There will be no change in T due to an initial angular error in elevation.

In the case of an elliptical orbit, the magnitude of the velocity of the satellite will change along the orbit. The difference between perigee and apogee velocities in feet per second is about 1.1 times the difference in perigee and apogee altitudes measured in thousands of feet. This difference amounts to about 4000 feet per second for an orbit with a perigee at 200 miles and an apogee at 800 miles.

On Applications of the Satellite Vehicle

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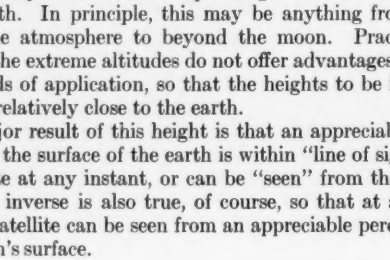
The fields where the satellite vehicle possesses potential usefulness include: Mapping and geodesy; Communications; Weather charting and forecasting; Research; Development of space flight. Broadly speaking, these fall into two groups; those which look "inward" from the satellite, toward the earth, and those which look "outward," away from the earth. It is not easy to demonstrate that there is any positive benefit to be gained from the outward-looking fields. On the other hand, the inward-looking fields can be analyzed in considerable detail, and the costs and benefits measured with quite reasonable accuracy. This paper is an introduction to the possibilities and problems of the inward-looking fields. To some extent it is a review paper, since none of the basic ideas presented is new.

Characteristics of the Satellite

THE characteristic of the satellite which makes it be potentially useful is its unique height above the surface of the earth. In principle, this may be anything from just outside the atmosphere to beyond the moon. Practically, however, the extreme altitudes do not offer advantages in any of the fields of application, so that the heights to be investigated are relatively close to the earth.

The major result of this height is that an appreciable percentage of the surface of the earth is within "line of sight" of the satellite at any instant, or can be "seen" from the satellite. The inverse is also true, of course, so that at any instant the satellite can be seen from an appreciable percentage of the earth's surface.



HEIGHT H MI	CENTRAL ANGLE θ	VISION ANGLEO	MAX SLANT RANGE D MI	VISION ARC S MI	PERIOD HOURS	% OF EARTH VISIBLE
57.3	20°	160°	705	1400	1.41	8
257	40°	140°	1445	2800	1.59	17
620	60°	120°	2310	4200	1.76	25
1210	80°	100°	3350	5600	2.06	32
2222	100°	80°	4750	7000	2.64	38
4000	120°	60°	6920	8400	3.95	43
7650	140°	40°	11000	9800	6.95	47
19000	160°	20°	22700	11200	19.30	49
22300	163°	17°	26800	11600	24.00	49.5

Fig. 1 Vision from the satellite

(*Note:* heading of third column should read: "vision angle θ.")

The geometry of this and numerical values of some of the parameters of interest are shown in Fig. 1. It is seen that the vision area is large even for very moderate heights. For example, at 257 miles altitude, the arc of vision extends across the width of the United States.

It cannot be expected that all of this enormous vision area will be useful, since the line of sight is very near grazing incidence at ranges near the maximum. This is shown in Fig. 2, which shows the elevation angle of the station as seen from the earth's surface for various altitudes and distances from the point directly beneath the station (substation point). For example, if 45 deg is considered to be the minimum useful elevation angle, the useful coverage is reduced to about $^1/_3$ in range or about $^1/_9$ in area, compared to the maximum coverage. This useful coverage probably varies with the application and is a problem which requires further study.

As a result of the orbital motion of the satellite, the area visible is, in general, continually changing. The factors which influence the resultant coverage are the orbital altitude, the direction of satellite motion, the inclination of the satellite orbit to the equator, and the rotation of the earth. The resultant of these influences can be shown by coverage charts.

Fig. 3 shows the track of the substation points for four successive revolutions of a 2-hour polar orbit. At the equator, these are separated by two hours, or 30 deg of longitude, or 1800 nautical miles. Due to the chart projection used, the

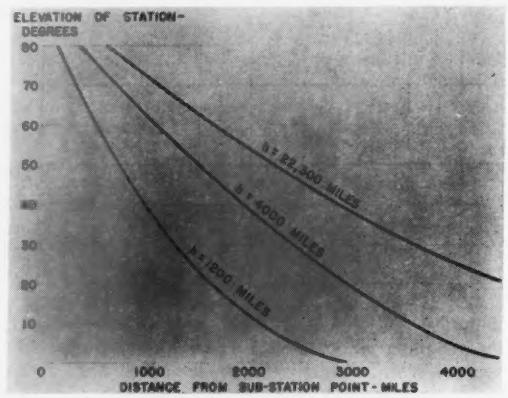


Fig. 2 Elevation angle of the satellite

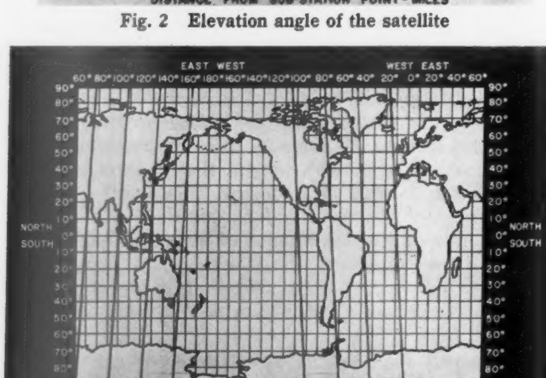


Fig. 3 Satellite tracks—2-hr polar orbit

(*Note:* the phase "westward motion" in above fig. should read "northward motion.")

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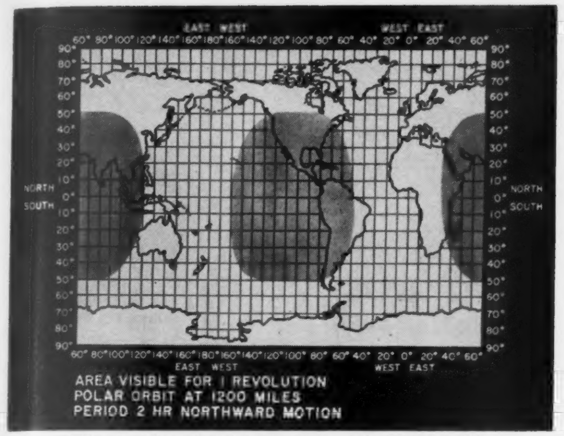

Fig. 4 Line of sight coverage—2-hr polar orbit

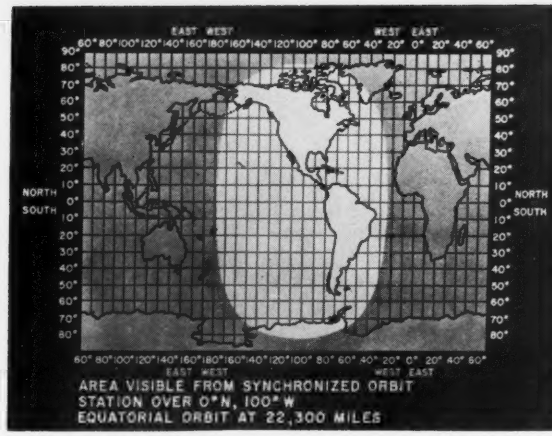

Fig. 6 Line of sight coverage—24-hr synchronized orbit

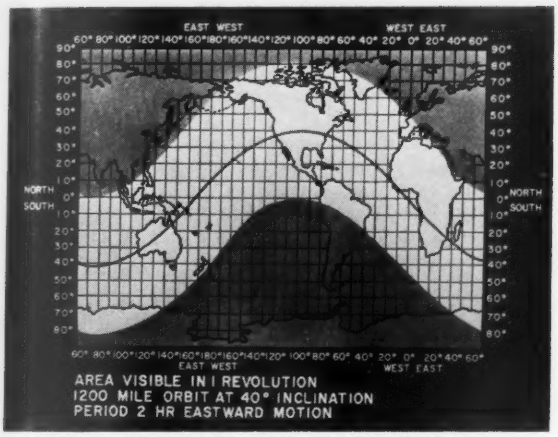

Fig. 5 Line of sight coverage—2-hr inclined orbit

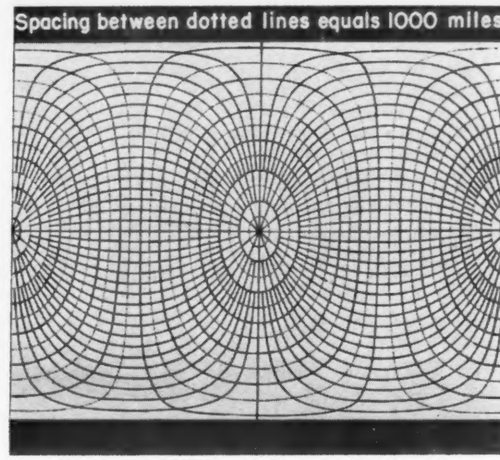

Fig. 7 Great circle paths for world projection

tracks appear to maintain constant spacing, but on the earth's surface they join at the poles.

Fig. 4 shows the areas which are within maximum line of sight vision for a single revolution of the same satellite. On the next revolution this pattern is displaced 1800 nautical miles to the west. If this displacement is repeated several times, corresponding to several revolutions, it will be found that any point on the earth's surface will be within "sight" of the station on eight of the twelve revolutions which occur in a day, and that the elevation angle will be large for four of these. Since two of these four "passes" occur during hours of darkness, the station attains effective daylight coverage for two successive passes in the course of one day.

The effects of inclining the orbit are shown in Fig. 5. Here the period remains at two hours, but the plane of the trajectory is inclined at 40 deg to the equator. Trajectories of this type reduce the coverage near the poles, and increase it near the equator.

With the station on a 24-hour orbit at the equator, it can be synchronized with the earth to remain always above the same equatorial point. Fig. 6 shows the coverage which results if the substation point is at 100 deg West longitude.

All of these examples are calculated for ideal conditions, with a circular orbit. In practice, some errors in circularity, period, and orbital plane must be expected. The effect of these is not great if the error is reasonably small. For example, for the synchronized orbit the libration introduced by a 1 deg error in the orbital plane reduces the reliable coverage on the surface of the earth by about 120 miles, out of about 6000 miles. However, for this case the period must be exactly synchronized with the earth's rotation whereas in other cases the period has little effect on the average coverage.

Studies of coverage are simplified by use of Fig. 7. Here the solid lines which intersect at the center of the chart are great circle paths. The "ovals," alternately solid and dotted, are range marks, the distance between dotted lines along a great circle path being 1000 statute miles.

Applications to Mapping and Cartography

Tombaugh and O'Keefe (1, 2)[2] have suggested that the satellite be used to establish a series of points in a triangulation survey. Since the satellite would be readily visible over long distance, it appears that this technique would be very valuable in tying together the normal surveys on separate continents and in making long distance triangulations where detail is not needed. Determination of the absolute value of g would also be possible.

However, it appears that simultaneous observation from the earth and the satellite will give better results, providing of course, that adequate resolution and coverage can be obtained.

The primary factor in the amount of resolution possible is the optical system used. Fig. 8 shows the theoretical limiting resolution for a number of systems (3). The 8-in. and 40-in. lens systems are typical of normal ground and aerial survey techniques. It is evident that these would not give much detail but that the resolution would be quite ample to map land masses, major waterways, and such features.

[2] Numbers in parentheses indicate References at end of paper.

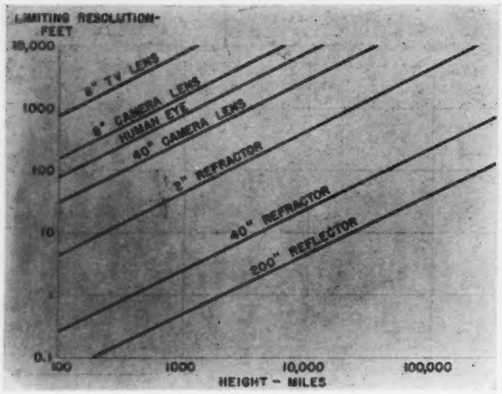

Fig. 8 Limiting resolution of optical systems

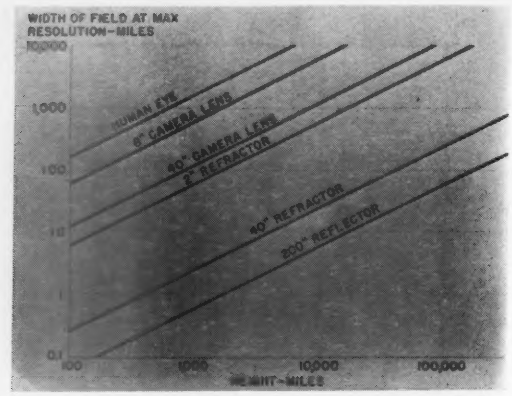

Fig. 9 Coverage of optical systems at limiting resolution

The high resolution group of optics are typical of astronomical techniques. For these the resolution is adequate to resolve fine natural detail and much cultural detail.

In this connection, it may be noted that in the highest altitude photographs to date, made with a short focal length camera from 158 miles on a Viking flight, the only cultural details which can be identified are railroads and runways of an airport (4).

It must be remembered that the coverage of a single shot becomes smaller as the resolution is increased. Fig. 9 shows the width of field obtained at maximum resolution for a number of systems, assuming a vertical view. It is evident that a large number of individual shots will be required to cover a large area.

For example, assume that an 8-in. focal length camera were used in the 2-hour orbit. Using 5-in. film, the coverage would be about 1000 miles. Allowing for overlap, a single track about the earth would require about 50 shots. Since, for a polar orbit the spacing of successive tracks is about 2000 statute miles, three cameras would be required to give complete coverage with overlap. To completely cover the earth in daylight would involve taking 900 photographs.

It is evident that recovery of the photographic information will be quite a problem. Since physical recovery appears to be quite a way in the future, initial work will have to be confined to television and facsimile techniques.

The resolution of television is about 400 lines, and of facsimile about 1000 lines per inch. As shown in Fig. 8, in using an 8-in. lens the effective resolution would be reduced to about $^1/_5$ of the limiting resolution for television, with practically no reduction for facsimile. In view of this, it appears possible to secure useful cartographic information with these techniques.

It appears that the following conclusions regarding application of the satellite to mapping and cartography can be justified:

1 In the initial stage, the satellite would be used as a reference point, to tie together normal surveys, and to form special operations, such as determinations of the absolute value of g.

2 In a later stage, the satellite would be used with television and facsimile techniques to make low-detail large area investigations, usually of less explored regions, but also of regions which are subject to change.

3 In the final stages of development, after physical recovery is perfected, the satellite would be used in the preparation of high-detail high-accuracy charts. The broad coverage and resolution possibilities indicate that this service would replace many conventional methods of charting.

Applications to Communications (Refs. 2, 5–9)

When considering the satellite and the field of communications, it is apparent that electro-magnetic radiation must be used and that the frequency employed must be located in a

TYPE OF SERVICE	SERVICE LEVEL	COVERAGE	WAVELENGTH - Cm	POWER OF GROUND TRANSMITTER - WATTS	SIZE OR TYPE GROUND ANTENNA - FEET	TYPE SATELLITE STATION	HEIGHT OF SATELLITE MILES	POWER OF SATELLITE TRANSMITTER - WATTS	SIZE OF SATELLITE ANTENNA - FEET	BANDWIDTH - Mc	NOTES
PULSE RELAY	MIN	49%	10	10^7	250	PASSIVE	22,000	0	1000	5	REF. (2)
PULSE RELAY	MIN	49%	10	10^5	250	PASSIVE	620	0	100	5	REF. (2)
PULSE RELAY	MIN	49%	10	100	250	ACTIVE	22,000	3×10^{-2}	10	5	REF. (2)
FM RELAY	100:1 S/N	100 mi.	15	4	250	ACTIVE	22,000	4	100	0.15	
TV RELAY	100:1 S/N	100 mi.	15	400	250	ACTIVE	22,000	400	100	6	
FM BROADCAST	RURAL	49%	300	—	YAGI	XMTR	22,000	1.5×10^3	40'	0.15	(50 uv/m)
FM BROADCAST	URBAN	49%	300	—	YAGI	XMTR	22,000	6×10^3	40'	0.15	(100 uv/m)
TV BROADCAST	RURAL	49%	150	—	YAGI	XMTR	22,000	1.5×10^5	20'	6	(500 uv/m)
TV BROADCAST	URBAN	49%	150	—	DIPOLE	XMTR	22,000	1.5×10^7	20'	6	(5000 uv/m)
TV BROADCAST	URBAN	USA	150	—	DIPOLE	XMTR	22,000	1.3×10^4	320'	6	(5000 uv/m)

PERCENTAGE COVERAGE IS PERCENT OF EARTH SURFACE COVERED

Fig. 10 Satellite communication systems

zone where the atmosphere is transparent. This limits the possibilities to the optical band, to parts of the infrared band, and to the radio frequency range between about 1 cm and 500 cm wavelength.

The fact that the only frequencies which can be employed by the satellite are not useful for present long-range communication seems to offer attractive possibilities in reducing the congestion which exists at present in useful long range communication channels. On a percentage basis, the spectrum available for long-range transmission is about doubled, and on an absolute basis is extended by perhaps a factor of 1000, so that the potential degree of expansion is very great.

Fig. 10 shows a tabulation of a number of possible applications to communication services, and also the level or quality of service which results from various combinations of equipment.

It is evident that the technical requirements for minimum communication channels are quite small. This indicates that there is no great problem in communicating data which originate at the satellite, since the deficiencies of modest satellite equipment can be compensated for by high-quality ground installations.

On the other hand, it is evident that marked reduction in the requirements for ground equipment must be secured by increasing the complexity of the satellite borne equipment. In some cases this is small, as, for example, in the point to point relaying of signals. This suggests that the satellite will be useful in this field.

However, it must be remembered that the satellite must compete on an economic basis with services now in existence. The problems thus introduced are complex and must be examined in detail before final answers can be given. Such preliminary studies as have been made (2, 9) indicate that the satellite must be nearly free of initial cost if it is to compete in the relay services. There are a few exceptions, of course, such as the transoceanic relaying of television signals, where present techniques are not adequate; but even these are marginal in cost.

It appears that there are only two situations in which the use of the satellite can be justified. One may arise from the demand for communication channels, which may justify increased costs. This demand exists now, and is chronic, as is evident to anyone who has followed the various International Telecommunication Conventions (10). However, to date it has been possible to accommodate the demand by improvements in communication efficiency, and it appears that this improvement may continue for some time.

The other situation is the use of the satellite for those general coverage services which are forced to the high line-of-sight frequencies by their characteristics (5). With present techniques, these require extensive duplication of transmitting facilities. Considerable economies appear possible if these scattered facilities could be consolidated, as is possible with the satellite. At the same time, service could be improved and extended.

In any event, it appears that any extensive application of the satellite to communications will require a rather high degree of development of the satellite. It is possible that an adequate degree of development can be secured with unmanned operation, but the problem of servicing equipment to assure reliable operation indicates that manned operation will be preferable.

These considerations indicate that full application of the satellite to communications is sometime in the future. This, however, should not be regarded as justification for ceasing study of the application. The possibilities are so great that continued study is in order.

Applications to Weather Charting and Forecasting (Ref. 11)

The prominence of clouds in the photographs made from rockets has suggested that observations from satellite vehicles would be of great assistance in weather charting and forecasting. The observational requirements for this application are very similar to those for mapping, except that great detail is of lesser importance. Review of the resolution and coverage curves of Figs. 8 and 9 indicates that television relaying is very useful, although the greater resolution provided by facsimile would be helpful for some measurements, such as cloud height.

The degree of coverage and the extent to which this is repeated during the day are of importance, since most of the short term variations in the weather occur in the temperate zones.

This suggests that polar or inclined orbits very near to those of Figs. 4 and 5 would be optimum, since these offer good coverage. Altitudes between 1000 and 4000 miles appear suitable, with the higher ones appearing somewhat better.

Wexler (11) has suggested that the application should include other measurements than cloud coverage. The data he suggests are: (*a*) Surface temperature; (*b*) approximate atmospheric temperature; (*c*) precipitation area; (*d*) thunder storm area; (*e*) solar radiation; (*f*) albedo of the earth; (*g*) density of meteoric dust.

All of these measurements are readily accomplished by either optical or radio scanning, or normal telemetry techniques.

It appears that the requirements for this application can be satisfied quite readily with an unmanned satellite of quite modest payload. About the only specialized requirements would be stabilization of the scanners, and adequate service life. The need for additional developments would not be great, although recovery and eventual manned operation could give improved service.

Initially, of course, the service would have to be regarded as experimental, with the data used to supplement those obtained by present techniques. As more reliable operations were secured it would be possible to suspend some of the present techniques, such as the Weather Ships, the Iceberg Patrol, and the Hurricane Hunter flights. Eventually, it would appear possible to rely on the satellite service and automatic weather stations for all primary data. During this process, it would be reasonable to expect that the accuracy, scope, and anticipation of the forecasts would improve.

Summary and Conclusions

It has been seen that the satellite vehicle has applications in each of the three inward-looking applications covered. In each application, there are some characteristics in which the satellite is unique. In others, the satellite resembles present-day conventional techniques, and must compete with these.

The steps in the development of the applications appear to be:

1 An early stage, with some applications to weather charting, and the beginning of cartographic work.

2 An intermediate stage, with the weather and cartographic work being improved and expanded, and with the beginning of communication applications.

3 A final stage, with the weather and cartographic work replacing and extending much of the current technique, and with the satellite service competing with current communication techniques.

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2 ARS Space Flight Committee, "On the Utility of an Artificial Unmanned Earth Satellite," Jet Propulsion, vol. 25, February 1955, pp. 71–78.

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4 Baumann, R. C., and Winkler, L., "The Earth Photographed from 158 Miles Up," Research Reviews, Office of Naval Research, February 1955, pp. 16–18.

(*Continued on page 368*)

Control and Power Supply Problems of Instrumented Satellites

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Schemes for an attitude control system and for electric power supplies for an unmanned satellite of a few hundred pounds total weight are presented. The attitude of the satellite with respect to the earth's center is controlled within plus or minus 10 deg by utilizing the shadowing effect of the earth on the isotropic cosmic radiation. A number of Geiger counters are arranged so that they sense the location of the shadow cone of the earth. Signals resulting from the counting rates of the counters control flywheels that cause the satellite to rotate around its center of gravity. Three sources for electric power are described, each of which delivers an average of about 100 watts. The first converts the sun's radiating energy with a silicon junction photoelectric generator. A sun-seeking device keeps the generator oriented toward the sun during daytime. In the second system, the sun's radiation is directed toward a pile of thermocouples made out of ZnSb and constantan. Thermocouples have been built out of these materials which convert solar energy into electric energy with an efficiency of 5.6 per cent. The third method uses a radioactive isotope, strontium 90, and its daughter product, yttrium 90, as heating element for a pile of thermocouples. The half life of strontium 90 is 20 years. Each of these three sources has a specific power production of the order of 0.4 to 0.7 watts per pound of weight. The attitude control system and the methods of power supply described are applicable also to larger satellites. If the total power to be provided is of the order of 20 kilowatts or more, a steam-electric generator with the sun, a radioactive isotope, or a nuclear reactor as heat source becomes more efficient than the systems described here. For a total operating time of only 2 or 3 days, dry cell batteries are preferable to any other system at power levels up to a few hundred watts.

1 Introduction

BEFORE the final goal of satellite development, the manned satellite, can be attacked, a number of basic problems connected with artificial satellites must be solved. The technique of multistage rockets as carrier vehicles must be developed; the stability of motion of an orbiting body under the influences of the moon, the tides, the equatorial belt, and also the residual air drag must be studied; means to observe and track the satellite from the ground must be investigated; methods of communication and data transmission between earth and satellite must be developed; the action of cosmic rays, meteors, meteoric dust, and ultraviolet rays as present in outer space must be determined.

In addition to these investigations which are absolutely necessary before a manned satellite can be established, a number of observations of highest value will be possible with an unmanned satellite. Among these are more accurate measurements of all kinds of radiations; magnetic measurements; measurements of the earth's reflectivity; weather observations for extended forecasts; intercontinental surveying; televised pictures of the earth with cloud and dust formations; radio and television relay stations between continents; and others.

2 Minimum Instrumentation of a Satellite

As soon as observations must be made onboard the satellite, instrumentation and a power supply are necessary. Measuring data on solar and cosmic radiations, impact of small meteors on a microphonic test plate, reflected radiations from the earth, and other observations are recorded on a magnetic tape until the satellite passes over a receiver station on the ground. Upon a trigger signal from the ground station, the recorder runs backward at high speed and plays out the stored information within one or two minutes. A pulse transmitter sends the data down to earth. To facilitate the analysis of measuring data and also the transmission of signals, the satellite should have a definite orientation in space.

A proposal for a minimum orbital unmanned satellite with instrumentation has been presented by F. Singer (1).[2] Its total weight is between 50 and 100 lb. Electric power of the order of 5 to 10 watts is produced by a silicon junction photoelectric generator irradiated by the sun. To maintain a fixed attitude in space, the cylindrical body rotates around its longitudinal axis and thus stabilizes its initial orientation. The satellite orbits around the earth in such a plane that one basis of the cylinder, which carries the silicon disks, constantly faces the sun. If the release of the gyrating satellite from the carrier rocket occurs smoothly, the direction of its rotational axis will remain fixed with respect to space, so that after three months the sun's direction will be perpendicular to the sensitive direction of the silicon disks. But for at least a few weeks, the silicon generator will supply power. The receiving station on the ground must be powerful enough to transmit and receive the signals, even though the satellite has no directional antenna.

3 Instrumentation for Higher Requirements

For more accurate observations which include the directions of cosmic, solar, and earth-reflected radiation, the satellite should be oriented such that its main axis constantly points to the center of the earth. This earth-fixed orientation would allow a much more efficient and more powerful data-transmitting system. Furthermore, it would provide a more realistic simulation of the operating conditions of a manned space station. Even though the angular accuracy of this orientation would not be greater than about 10 deg, the use of a directional antenna with a beam width of about 30 deg would be possible. The onboard power supply should provide an average power of the order of 100 watts. The instrumentation of this "advanced" satellite should be capable of continuous operation through at least several months. Also, the attitude control system and the power supply

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[1] Head, Technical Feasibility Studies Office, Ordnance Missile Laboratories.

[2] Numbers in parentheses indicate References at end of paper.

should work in such a way that they function correctly in any plane of orbit.

It appears feasible to build a satellite with a total weight of 300 to 500 lb which meets these requirements.

4 Attitude Control System

The problem of keeping, over a period of months, the main axis of the satellite directed toward the center of the earth, independent of altitude, time of orbiting, plane of rotation, day or night, cannot be solved with gyroscopic means alone. It seems possible, however, to utilize the shadowing effect of the earth on the isotropic component of the cosmic radiation to obtain a signal onboard the satellite which indicates the instantaneous location of the earth. The principle of this method is illustrated in Fig. 1. It shows the earth, the satellite S, and a set of Geiger counters which are arranged and shielded in such a manner that they count predominantly cosmic rays arriving in the direction indicated by the arrow. If the set of counters as shown in Fig. 1 is slowly rotated around S, and if the counting rate is plotted for each angular position, an angular intensity curve will be obtained as indicated in the figure. The intensity shows a rapid drop as soon as the counters enter the shadow of the earth. If the effective cross section of the counters is sufficiently large, the counting rate will be high enough to represent a fairly smooth signal. Some integration

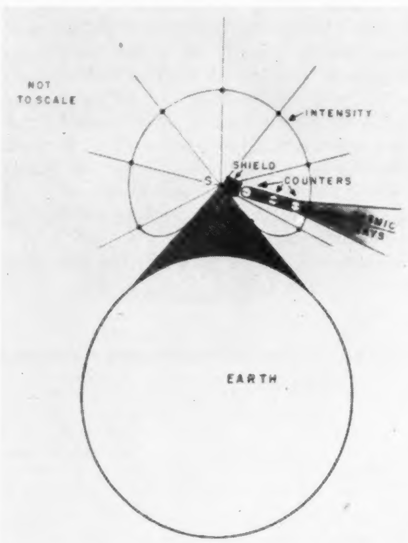

Fig. 1 Earth's shadow effect on cosmic ray intensity

of the counting rate is permissible since the response time of the control system need not be shorter than $^1/_2$ to 1 minute.

The complete attitude control system employs two sets of directional counters as indicated in Fig. 2. They are arranged so that their axes point into the directions of maximum intensity gradients. The difference between the counting rates of the two sets provides the controlling signal. It is zero as long as the satellite's axis points to the center of the earth, since in that position the counting rates are equal. Upon an angular deviation, the differential counting rate increases with a polarity depending on the direction of the deviation.

The angular definition of the sensitive direction of one set of counters is not better than about plus or minus 10 deg, so that even a substantial variation in altitude of the satellite would be covered by the same angular arrangement of the two sets. The scheme illustrated in Fig. 2 would be used twice to control the attitude of the satellite in two planes which are perpendicular on each other.

Although little is known as yet about the directional distribution and intensity of cosmis rays at an altitude of several hundred miles, it is to be expected that in a direction tangent to the surface a marked intensity gradient will be experienced.

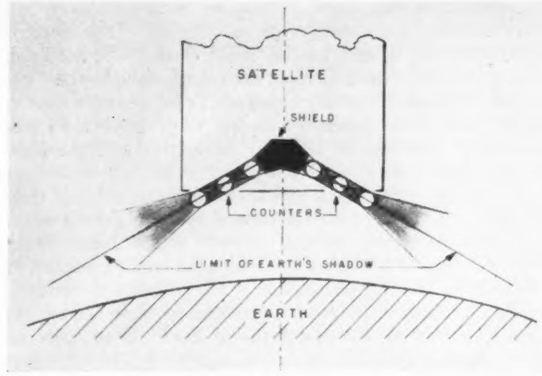

Fig. 2 Direction-sensitive arrangement of cosmic ray counters

An angular control movement of the satellite in either one of the two control planes as required by the error signals from the Geiger counters is carried out by two flywheels. As soon as an error signal is large enough, it energizes a relay which starts the d-c motor of the corresponding flywheel in the desired direction. The conservation of angular momentum causes the satellite to turn in the opposite direction around its center of gravity. When the desired attitude of the satellite is reached, the signal reduces to zero and the relay opens. If in this moment the flywheel is braked, either electrically or mechanically, to zero velocity, its rotation and the rotation of the satellite cease simultaneously. The entire kinetic energy of the flywheel and satellite is dissipated in the brake. In this way, a stable operation of the attitude control system is possible without using derivatives of the error signals for damping purposes.

Since the magnetic field of the earth has a very noticeable deflecting effect on the softer components of the cosmic radiation, the attitude control system should respond only to the energetic component which is almost isotropic.

If an arrangement of Cerenkov counters were used instead of normal Geiger counters, the selection of a desired energy and of unidirectional cosmic ray particles would be greatly facilitated.

5 Power Sources for Satellite Instrumentation

If only a few days' operation of satellite instrumentation is contemplated, dry cell batteries may be used as a power source. They have the advantage of simplicity and reliability. The best batteries available today deliver about 50 watt-hr per lb. A comparison between batteries and photoelectric generators shows that a battery with the same weight and the same electric power output as a photoelectric generator lasts for about 60 hr. This figure is independent of the power level.

A survey of power-generating systems using an internal combustion engine with fuel and oxidizer as prime mover for an electric generator indicated that, at power levels of a few hundred watts, the system would deliver about 50 watt-hr of electric energy for each pound of fuel plus oxidizer. This figure is the same as for dry cell batteries. The weights of engine, generator, and cooler, are not even considered in that figure. If the complicated system of a power plant consisting of a combustion engine, fuel tanks, pumps, regulators, cooler, and generator, is taken into regard, the dry cell appears preferable by far.

When the satellite instrumentation must operate through more than a few days, other power supply systems have to be used. Two different primary power sources appear promising. The first is the sun, either energizing silicon junction photoelectric generators or heating a pile of thermocouples.

The second is a "hot brick," consisting of an artificial radioactive isotope, for example, strontium 90. This element emits beta rays; it has a half life of 20 years. The hot brick would serve as a heating element for a thermocouple pile.

A nuclear fission reactor as heat source for a satellite power supply holds some promise. Reactors operating with fast neutrons do not require a bulky moderator and therefore are small and compact. However, they have two distinct disadvantages which make, at least at the present time, their successful use on a small unmanned satellite questionable. The first is the strong gamma radiation which makes heavy shielding necessary in order to protect the radiation-sensitive instruments onboard the satellite. The second is the complicated control apparatus which is needed to make the reactor operate reliably at a constant power level. Both these requirements can probably be met without too severe difficulties onboard a large manned satellite which is assembled in space and which starts its operation while orbiting under constant conditions. For a small satellite which must be transported as a whole into its orbit, and which must operate there without any supervision and maintenance, it is extremely important that its instrumentation be as light, simple, reliable, and rugged as possible.

The possibilities of a direct conversion of radioactive energy into electric energy by means of semiconductors has been studied at Bell Telephone Laboratories (2). With silicon junctions and radioactive beta rays, efficiencies of a few per cent were obtained. Unfortunately the silicon junctions are damaged so seriously by the impact of high-speed electrons that the use of radioactive generators for satellite power supplies does not appear practical today.

A Photoelectric Generators

Silicon junction photocells have been developed recently with a surprisingly high efficiency (2). A thin layer of silicon of one square meter area produces 50 watts electric power if irradiated by direct sunlight. On the basis of information from publications, the following scheme for a photoelectric power generator has been devised.

A sheet of aluminum with an area of about 40 sq ft is covered with silicon junction photoelectric elements. They are connected in such a way that they deliver a voltage of about 60 volts if irradiated by direct sunlight. The maximum power output of this photoelectric generator is of the order of 200 watts. The rear side of the aluminum sheet is painted black. In full sunlight the equilibrium temperature of this generator will be about +50°C.

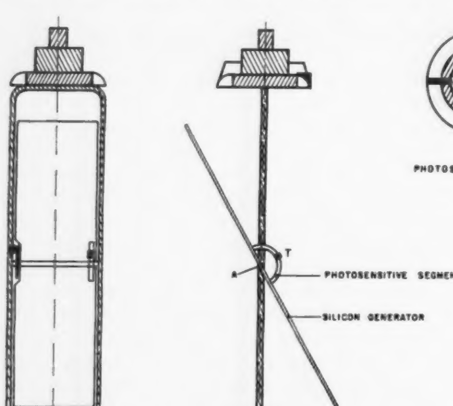

Fig. 3 Satellite with photoelectric power supply

The generator must be oriented toward the sun by a sun-seeking device. The scheme of this device is illustrated in Fig. 3. The generator can turn around a shaft A. A ring which is mounted on the satellite carries a photo-sensitive surface subdivided into two halves P_1 and P_2. At point S between the two halves, a photocell is mounted with a slot in such a way that it responds when the sun hits the ring perpendicularly at point S. Another photo-sensitive surface and a photocell T with slot are attached to the segment V; this segment is mounted on the generator. As soon as the satellite emerges from the night side of the earth and enters the day side, the sun irradiates the ring. The photoelectric signal from the surface P_1 or P_2 starts the motor of a flywheel with vertical axis in one or the other direction and consequently rotates the satellite around its vertical axis. As soon as the sun rays impinge on slot S, the flywheel and thereby the satellite are stopped in their motions. A similar procedure occurs at the segment V. The signal from there energizes a small motor which turns the photoelectric generator around its axis A. This turning motion is stopped when the sun hits the photocell behind slot T. The generator then exactly faces the sun. The simultaneous rotation of the entire satellite which occurs as a reaction to the generator's rotation is cancelled by the attitude control system of the satellite.

The generator carries instruments measuring radiations from the sun. Other instruments are indicated in Fig. 3. The Geiger counter sets for attitude control are mounted above the dish antenna which receives and transmits signals from and to the ground station. A storage battery supplies power during the satellite night; it is charged by the photoelectric generator during the satellite day. Alternating current is provided by a transistor inverter. It transforms d-c into a-c with an efficiency of about 90 per cent. Amplifiers, receivers, and transmitters are transistorized as much as possible to save power and weight.

Approximate weight data of a satellite with photoelectric generator are listed in Table 1.

Table 1 Partial and total weights of satellites
Electric power (average): 100 watts

	Photo-electric	Sun and thermocp	Isotope and thermocp
Frame	50	50	50
Mirror	..	160	..
Cooler with oil	..		100
Thermocouples	..	60	20
Heat source	..	..	50
Absorber	..	..	100
Photoelectric generator	120	..	..
Instrumentation with recorders	60	60	50
Transmitters	30	30	30
Flywheels	60	60	40
Storage battery	30	30	20
Total	350 lb	450 lb	460 lb

Although the feasibility and efficiency of a photoelectric generator of the silicon junction type are well established, its proper functioning over a period of months is not yet proved. All semiconducting photoelectric cells are known to deteriorate to some extent under the direct impact of sunlight. Efficient protection against radiation damage is a primary requirement to be met by the photoelectric generator before it can be used as a reliable power supply for satellite instrumentation.

B. Thermocouples with Sun Mirror

The second method to produce electric power onboard a

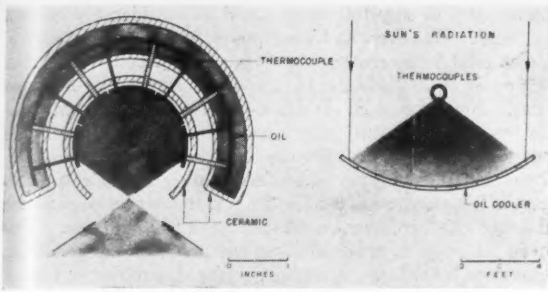

Fig. 4 Sun mirror and thermocouples

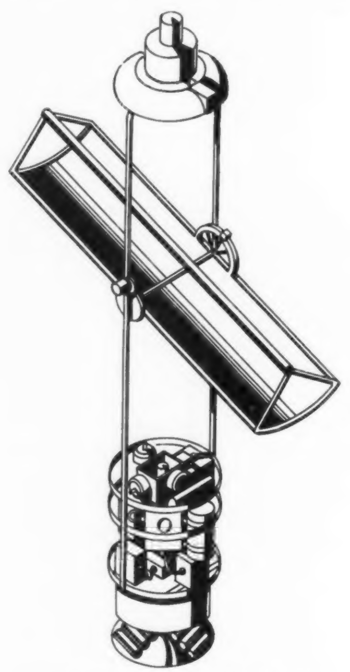

Fig. 5 Over-all view of a satellite with sun mirror and thermocouples

satellite uses thermocouples. Heat source is the sun. Its radiation is collected by a parabolic mirror and concentrated on a pile of thermocouples. The cold junctions of the couples are cooled by oil which dissipates its heat in a radiation cooler.

It should be noted that every power generator which employs heat as primary source of energy requires a cooler. The efficiency of the power conversion is proportional to the temperature difference between the hot and the cold end of the system; therefore, the cooler should keep the temperature of the cold end as low as possible. A cooler in empty space can dissipate heat only by radiation. The amount of heat that can be dissipated by a given cooling area is proportional to that area, to the fourth power of the absolute temperature, and to a coefficient which depends on the color of the cooling surface. If a cooling area of 10 sq ft with black surface radiates 1 kilowatt of heat into empty space (without being hit by the sun's radiation), it assumes a temperature of about +100°C. If it has to dissipate 2 kilowatts, its temperature is +170°C. If the cooler temperature is to be as low as +20°C, an area of 27 sq ft will be required to dissipate 1 kilowatt of heat. In all practical cases, the weight of the cooler alone will be more than half of the total weight of an electric power source which uses heat as prime energy.

The most promising materials for thermocouples are ZnSb with a few additives for the positive, and constantan for the negative component (3). At a temperature difference of 400°C, the voltage per couple and the efficiency have been found to be 0.1 volt and 5.6 per cent.

One possible way to arrange mirror and thermocouples is indicated in Fig. 4. The hot junctions of the couples form the inside of a cylindrical cavity which is located in the focal line of a parabolic mirror. The length and thickness of the thermocouple components between hot and cold junctions are chosen so that the flow of heat produces the desired temperature at the hot junctions. The cold junctions are surrounded by a cooling jacket. The cooling oil, which is pumped through the cooling jacket, dissipates its heat in a radiation cooler. This cooler is integral with the mirror; its rear side is blackened, its front side mirrorized. If the mirror and cooler have equal areas as shown in Fig. 4, the average temperature of the cooling oil during daytime is about +90°C. If the cooler area is enlarged in such a way that the cooling surface is not hit by either the sun's radiation or radiation from other parts of the cooler, the oil temperature will be lower. With a cooler area twice as large as the mirror, the temperature will be about +45°C.

An over-all view of a satellite with sun mirror and thermocouples is shown in Fig. 5. With an average power of 100 watts, the weight of the power supply amounts to about 250 lb. The total weight of the satellite would be of the order of 450 lb.

The sun-seeking device for this arrangement is the same as that described in paragraph 5A.

C Thermocouples Heated by Radioactive Isotopes

The third method uses thermocouples heated by radioactive isotopes. The cold junctions of the couples are again cooled by oil which dissipates its heat in a radiation cooler.

The radioactive isotopes to be selected should have a half life of several years. They should emit energetic beta rays, but no primary gamma rays. They should be readily available as a by-product from nuclear reactors. The most suitable element seems to be strontium 90, which emits beta rays of 0.54 MeV maximum energy and decays into yttrium 90 with a half life of 20 years. Yttrium emits beta rays of 2.2 MeV maximum energy. Its half life is 62 hr. A few days after the end of the formation of strontium 90, there will be radioactive equilibrium between strontium and yttrium. Beta rays with maximum energies of 0.54 MeV and of 2.2 MeV will be emitted at equal rates with a half life of 20 years. The beta rays are absorbed within the bulk of strontium and the container walls, their kinetic energy being transformed into heat. The temperature to which the block of strontium heats up is a function of the heat generated and the heat conducted away. The heat generated within one pound of strontium-yttrium per sec amounts to 50 watts, assuming that 8 per cent of the strontium extracted from the fission products of a nuclear reactor represents strontium 90 (2). With an efficiency of the thermocouples of 5 per cent, 2.5 watts of electric power will be produced by every pound of strontium-yttrium. For a power output of 100 watts, a total of about 40 lb of strontium-yttrium will be needed. The arrangement of heating element, thermocouples, and cooling jacket is

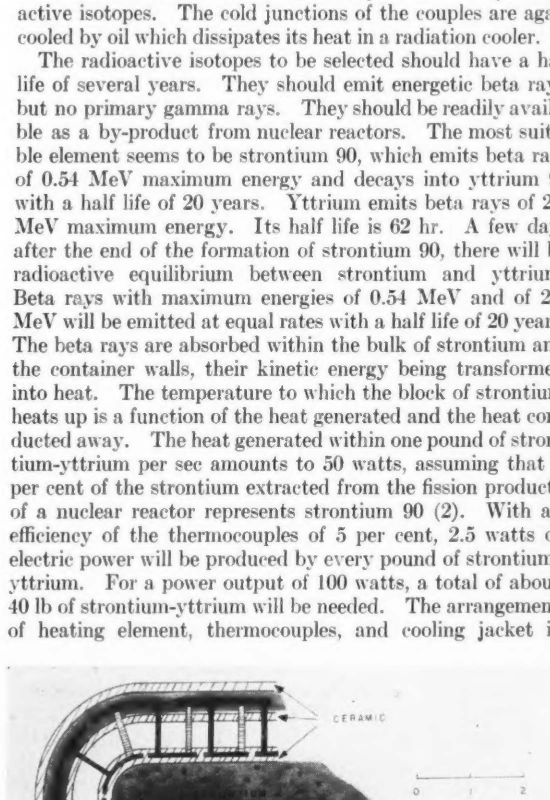

Fig. 6 Cross section through heat source and thermocouples

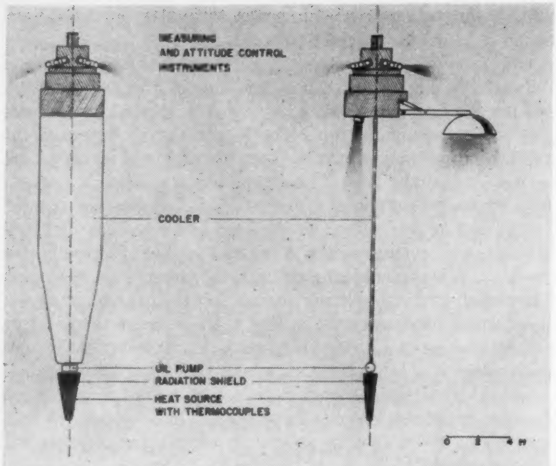

Fig. 7 Satellite with radioactive heat source and thermocouples

shown schematically in Fig. 6. The cooling oil is pumped through the radiation cooler by means of a little motor. To avoid leakage through gaskets, the cooling system including pump and induction motor is completely sealed.

The radiation cooler, built out of sheet aluminum with black outside, has the shape of a thin plate. Since it has no definite orientation with respect to the sun, it may be hit by the sun's radiation on one side. The total heat to be dissipated is about 2 kilowatts. If the cooler has a size of 40 sq ft, the maximum temperature it would assume when perpendicularly hit by the sun is about +80°C. If the sun is on edge, or at night, its temperature will be about +3°C. Its average temperature over day and night will be of the order of +20°C.

Although strontium 90 and yttrium 90 do not emit primary gamma rays, they represent a very intense source of secondary gamma rays and x-rays which are generated during the slowing down of the beta rays. The Geiger counters and the radiation-sensitive instruments onboard the satellite must be carefully protected against these gamma rays and x-rays. This protection will be achieved, first, by mounting the heat source as far away from the other instruments as possible, and second, by inserting an absorber between the heat source and the rest of the satellite. A schematic sketch of the arrangement of the components onboard the satellite with thermocouple generator is shown in Fig. 7. Approximate weight data for this satellite are listed in Table 1.

A radioactive heat source as outlined in this paragraph would, in all probability, not be available today. To produce 40 lb of strontium 90, more than 1000 lb of uranium or plutonium must be burnt in a nuclear reactor and processed for extraction of the strontium. As far as is publicly known, these figures surpass by far the amounts of radioactive isotopes from nuclear piles that are processed today. If an isotope of shorter half life were chosen, such as strontium 89 (53 days; maximum beta energy 1.5 MeV), about 20 lb of uranium or plutonium would have to be burnt and processed for a sufficient amount of radioactive strontium 89. Although this is still a very large amount of fissionable material, a radioactive heat source holds promise for the future when plutonium breeders are in operation and a larger number of high-power reactors are available from which the isotopes can be extracted.

6 Conclusion

The efficiency in converting the primary power into electric power is of the order of 5 per cent for either one of these three methods. For each watt of electric power, a weight of $1^1/_2$ to $2^1/_2$ lb must be invested. If a steam engine with an electric generator were used to convert heat power from the sun or a radioactive isotope into electrical power, the efficiency at a power level of only 100 watts would be considerably below 5 per cent. However, at higher power levels the efficiency of steam-electric generators improves. For a power output of the order of 20 kilowatts, it may be as high as 10 or 15 per cent. Heat for such a steam-electric generator may be derived from the sun, from a radioactive isotope, or from a small nuclear reactor. On the other hand, there are indications that the efficiency of semiconducting photoelectric cells can be increased considerably (2). If the danger of radiation damage can be overcome effectively, it is not unlikely that even for large manned satellites the photoelectric generator, energized by the sun, is superior to the steam-electric generator.

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A History of the Artificial Satellite

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A chronological bibliography of approximately 350 references, listing most of the significant published literature of artificial, manned or unmanned, satellites of the earth.

Introduction

THIS bibliography attempts to list all important published literature dealing with artificial, manned or unmanned, satellites of the earth. Bibliographical entries on such related topics as space medicine or rocket launching are included only if they consider directly satellite problems. On this basis it is not always easy to decide what should or should not be included (see, e.g., Schaub, "Der innere Marsmond . . .," 1953, or Whipple, "Harvard Meteor Program . . .," 1947).

Fiction also posed some problems. The literature of artificial satellites is not completely technical even at this late date. Some apparently useful concepts have been drawn from the speculations of novelists with no technical background. The boundary between science and art is even more indistinguishable in the early days of the science fiction novel. (See entries for Hale, Verne, and Lasswitz.)

Juvenile literature, for the most part, has been omitted. Semipopular works, especially the many German introductory works on space travel, have not been included comprehensively. Famous works on rockets (which deal with the question of artificial satellites and which have gone into more than one edition) have been listed, usually, under one of the later editions. Most works have been listed under the U. S. edition, but foreign editions and translations are available in many cases. Anonymous articles have been listed under the name of the publishing journal. Transliterations from the Cyrillic alphabet have been made according to the Library of Congress system, so that Ziolkowsky appears in this work as T͡siolkovskiĭ.

Most news reports have been omitted; only enough have been included to delineate the course of events. Extensive lists of nontechnical articles and news reports on artificial satellites can be located through such indexing services as the *New York Times Index*, the *London Times Index*, the *Public Affairs Information Service Bulletin*, the *Industrial Arts Index*, the *Readers' Guide to Periodical Literature*, and comparable services in different countries.

The legal aspects of this subject have not been treated thoroughly here. The extent of analogous legal material dealing with space law is larger than one might think at first. The following articles, which have been included here, provide many references to the literature: Haupt, "Die Rechtsstellung künstlicher Flugstützpunkte auf offener See," 1932; Cocca, "Die rechtliche Natur des Weltraums," 1955; Schäfer, "Die Fluginsel . . .," 1932; and Welf Heinrich, "Die Rechtsprobleme des Weltraumes," 1953 (a summary of a dissertation). Further legal articles can be located through the *International Law Quarterly*, the *Revue Française de Droit Aérien*, the *Zeitschrift für Luftrecht*, etc.

JET PROPULSION has undergone the following name changes during the past years: *Bulletin of the American Interplanetary Society*, June 1930–April 1932 (nos. 1–18); *Astronautics*, May 1932–December 1944 (nos. 19–60); *Journal of the American Rocket Society*, March 1945–December 1953 (no. 61—vol. 23); JET PROPULSION, January-February 1954, vol. 24 to date.

The *Journal of the British Interplanetary Society* started with vol. 1, January 1934, and has continued to date, with a lapse during the war years, publishing approximately two issues per year in its earlier days, and six times per year later.

Weltraumfahrt, organ of the Gesellschaft für Weltraumforschung (Stuttgart), started with vol. 1, January 1950, and has continued to date.

Information about the name changes and volume numbers of journals listed herein, can be verified in the *Union list of serials in the libraries of the United States and Canada*, or possibly in the *World list of scientific periodicals published in the years 1900–1950*, 3rd ed., New York, Academic Press; London, Butterworths, 1952.

The author's time did not permit more than a brief annotation for each item. With the exception of those few items marked with an asterisk, all have been inspected by the author; all are known to exist. In some cases, locating and borrowing some of these references proved to be rather difficult, often frustrating. In an attempt to inspect an early Russian book on rockets, the author tried writing to the Librarian of the Academy of Sciences, Leningrad, with negative results. The author can supply location information for all of the items listed herein.

Corrections and additions are solicited. It is anticipated that a supplement will appear within a short time.

BEFORE 1900

Hale, Edward Everett

The brick moon, and other stories, Boston, Little, Brown, 1899, 369 pp. The story "The brick moon" was published originally in the *Atlantic Monthly* in 1870 and 1871. It is the result of a plan conceived originally in 1838. In order to make easier the determination of longitude for navigators, it was decided to construct a brick moon to be launched by means of a pair of huge, water-powered flywheels into an orbit along the Greenwich meridian. The moon is launched, but because of the Magnus effect the orbit attained (5100 miles high) is not along the Greenwich meridian.

Lasswitz, Kurd

Auf zwei Planeten, Roman in zwei Büchern. Volksausgabe, Leipzig, B. Elischer, 1897. A science fiction novel in which is described, in the first few chapters, a "space ship" which remains stationary over the North Pole of the Earth. This ship is in the shape of a ring whose plane lies parallel to a tangent plane at the North Pole, at a height of one earth radius, 16,356 km. Ring is 120 meters in diameter with an opening in the center of 20 meters. Revolving outside the ring are several thin concentric rings forming a "system of flywheels, revolving about the inner ring (the space ship) at great speed, maintaining the plane of the space ship." The space ship is three stories high, containing mostly a tangle of wires, gratings, and vibrating mirrors. Whole system is built of material which is completely transparent but of extraordinary strength. The space ship is held up by the emission of an "Abaric field" from an artificial island at the North Pole. In some respects this represents an early concept of a space station.

Verne, Jules

Les cinq cents millions de la Bégum (Begum's five-hundred millions), Paris, Hetzel, 1879, 185 pp. Tale of guns within

Received January 28, 1956.

[1] Formerly Librarian of the Technological Institute Library. Present address, Library, Marquardt Aircraft Co., Van Nuys, Calif.

guns nesting telescopically. Missile intended to fall on another town attains velocity of 10,000 m/sec and becomes an artificial satellite owing to an error in calculation. Referred to in Rynin's "Mezhplanetnye Soobshcheniya."

1920's

Debus, Karl
Weltraumschiffahrt, ein poetischer Traum und ein technisches Problem der Zeit, *Hochland (München)*, vol. 24, Band 2, July 1927, pp. 356–371. Considers the development of the idea of space travel and other fantastic trips in literature, outlining a valuable bibliography of this subject.

Dittrich, Paul
Ist eine Fahrt nach dem Mond möglich? Urania; *Kulturpolitische Monatshefte über Natur und Gesellschaft* (Jena), vol. 3, no. 8, 1926–1927, pp. 241–242. Describes an orbital technique for getting to the moon. Slightly erroneous. Concludes that "space travel is also for the time being, and perhaps for all time, a fantastic dream!"

Gail, Otto Willi
Mit Raketenkraft in's Weltenall; vom Feuerwagen zum Raumschiff. Mit einem Vorwort von Max Valier und vielen Bildern, Zeichnungen und Originalphotographien, Stuttgart, K. Thienemanns, 1928, 106 pp. Discusses the Goddard "flying torpedoes," Oberth's space ship, the Gesellschaft für Raumforschung, Valier's project, etc.

Glushko, V. P.
Stansii͡a vne zemli (Station beyond the earth), *Nauka i Tekhnika*, Leningrad, vol. 4, no. 40, Oct. 8, 1926, pp. 3–4. Discusses Oberth's space mirror, including rough estimates of cost, use of satellite for gravity-free studies, astronomy and the use of satellites around other planets.

Ley, Willy
Die Fahrt in Weltall, 2nd rev. ed., Leipzig, Hachmeister and Thal, 1929, 83 pp., especially pp. 64–70. Die Aussenstation. Discusses the nature of a space station and Oberth's space mirror.

Ley, Willy, ed.
Die Möglichkeit der Weltraumfahrt; Allgemeinverständliche Beiträge zum Raumschiffahrtsproblem, Leipzig, Hachmeister and Thal, 1928, 344 pp. Contributions by Ley, Debus, Oberth, Pirquet, and others, especially "Stationen im Weltraum," by Oberth, pp. 216–239.

Linke, Felix
Die Verwandtschaft der Welten und die Bewohnbarkeit der Himmelskörper, Leipzig, Quelle & Meyer, 1925, 165 pp. Later pages review some early fiction and nonfiction dealing with space travel, e.g., Lasswitz' "Auf Zwei Planeten," and "Die Rakete zu den Planetenräumen." Deals mostly with an analysis of the physical elements of the universe and the possibility of life on other planets.

Noordung, Hermann
Das Problem der Befahrung des Weltraums, der Raketen-Motor, Berlin, R. C. Schmidt, 1929, 188 pp. General introduction to the space travel problem with a description of a space station consisting of three parts connected by cables, an observatory, a solar power plant, and a main station.

Oberth, Hermann
Die Fahrt in den Weltraum, *Die Umschau*, bd. 28, no. 12, March 1924, pp. 198–199. Discussion of space station as observation station in reference to article of same title by Riem in *ibid.*, bd. 28, no. 5, 1924.

Wege zur Raumschiffahrt . . . 3 Auflage von "Die Rakete zu den Planetenräumen," München und Berlin, R. Oldenbourg, 1923 and 1929, 431 pp. The Station in Space, part 4, chap. 20, pp. 350–353. Discusses location and purpose of space station.

Pirquet, Guido von
Fahrtrouten, *Die Rakete*, vol. 2, no. 8, August 1928, pp. 117–121; vol. 2, no. 9, Sept. 1928, pp. 134–140; vol. 2, no. 10, Nov. 1928, pp. 155–158. The importance of an artificial satellite as a stepping stone to space travel.

Die Rakete
Probekapitel aus Noordung: Das Problem der Befahrung des Weltenraums, vol. 3, no. 1, Jan. 15, 1929, pp. 7–9. Excerpts from the chapter "Das Wohnrad" in Noordung's book.

Riem, Johannes
Die Fahrt in den Weltraum, *Die Umschau*, bd. 28, no. 5, Feb. 2, 1924, pp. 71–75. Discussion of book, "Die Rakete zu den Weltenräumen," by Hermann Oberth, München, 1923. Page 74: "Man konnte . . . diese Raketen dauernd um die Erde herumlaufen lassen, als künstliche Monde." Suggested uses of satellites as observation stations or for mounting huge mirrors to reflect enough sunlight on the earth to de-ice and cultivate the North Pole.

Valier, Max
Raketenfahrt (5th ed. of Der Vorstoss in den Weltenraum), Eine technische Möglichkeit, Munich, Oldenbourg, 1928, 252 pp.

1930's

Baumgarten-Crusius, Artur
Die Rakete als Weltfriedenstaube, Leipzig, Verband der Raketen-Forscher und -Förderer, 1931, 174 pp. Pages 157–158: Discusses the use of orbital rockets for gathering meteorological information, for observing the earth with telescopes and Oberth's space mirror. This is a somewhat hysterical, anti-French book.

Biermann, Gerd
Weltraumschiffahrt? Eine kurze Studie des Problems, Bremen, F. Leuwer, 1931, 43 pp. Early history of the physical and technical problems of rocketry with a discussion of space travel.

Brügel, Werner, ed.
Männer der Rakete, in Selbstdarstellungen, Leipzig, Hachmeister and Thal, 1933, 144 pp. Articles written by Esnault-Pelterie, Ley, Oberth, Pirquet, Rynin, and others describing various aspects of rockets, satellites and space stations.

Cleator, Phillip E.
Rockets through space; the dawn of interplanetary travel, New York, Simon and Schuster, 1936, 227 pp. Discussion includes: Outward stations, pp. 128, 178 ff., and space mirror, pp. 175, 208.

Haupt, Günter
Die Rechtsstellung der Künstlicher Flugstützpunkte auf offener See, *Archiv für Luftrecht*, Institut für Luftrecht, Königsberg, bd. II, no. 4, 1932, pp. 297–311. Discusses the remarkably analogous legal aspects of a floating air base on the open sea; many references cited.

Hennig, Richard
Weltluftverkehr und Weltluftpolitik, Berlin, Zentral-Verlag, 1930, 67 pp. Discusses legal and political aspects of artificial island landing fields in the ocean, the arctic regions and the question of a vertical height boundary.

Lasser, David
The conquest of space, New York, Penguin Press, 1931. Description of Oberth's space station.

Manned rocket as satellite of earth proposed for permanent observatory use. German projects ships to move in own orbit 500 miles aloft. Supply craft would take food to "crew" and bring back data of observers. Startling venture is believed to be scientifically sound. *New York Herald Tribune*, Sunday Aug. 3, 1930, sec. IV, p. 3. Refers to early views of Oberth on a station in space.

Nebel, Rudolf
Raketenflug. Reinickendorf, Raketenflugverlag, Berlin, 1932, 47 pp. History of rockets and space travel, mentioning Verne, Lasswitz, Ganswind, etc.; reproduction of a news story which appeared in the *Berliner Tageblatt*, Nov. 2, 1930, announcing the plans of the Raketenflugplatz, pictures of same, description of the work there, and an early representation of a space station. Nebel was the Director of the Raketenflugplatz.

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Einführung in die Probleme der Weltraumfahrt, Vienna, Österreichische Gesellschaft für Raketentechnik, 1931. Especially lecture no. 4: Die Aussenstation.

Schäfer, Hans-Ulrich
Die Fluginsel; eine völkerrechtliche Studie über die Probleme der künstlichen Flugstützpunkte auf offener See, Göttingen, Vandenhoeck & Ruprecht, 1932, 79 pp. "Literatur-verzeichnis," pp. 77–79.

T͡siolkovskiĭ, Konstantin É.
Izbrannye Trudy. Moscow, ONTI NKTP SSSR GOSMASHMETIZDAT, 1934. Chief Editor, E. V. Latynin. Biographical outline by Prof. N. D. Moiseev.

Vol. I: "T͡sel'nometallicheskiĭ Dirizhabl'" (An all-metallic dirigible). Editor I͡a. A. Rapoport. Contains a chronological list of T͡siolkovskiĭ's works by Prof. N. A. Rynin.

Vol. II: "Reaktivnoe dvizhenie" (Reaction motion). Editor F. A. T͡sander. Contains 8 articles on reaction-motors aeronautics.
Art. I: "Rocket into cosmic space." Reference to satellites on p. 24 (mass ratio required) and p. 36 (trajectory calculations).
Art. II: "Exploration of world spaces with reaction apparatuses." Reference to satellites on p. 112 under "Plan for the conquest of interplanetary space."
Art. III: "Cosmic rocket. Experimental preparation." Description of rocket proposed by T͡s. Some fuel computations.
Art. IV: "Cosmic reactive trains." Description of various systems of multistage rockets.
Art. V, VI, VII, VIII on aeronautics.
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***Symposium over Raketten**

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2. Extraterrestrial instrument vehicle
3. One-man research rocket

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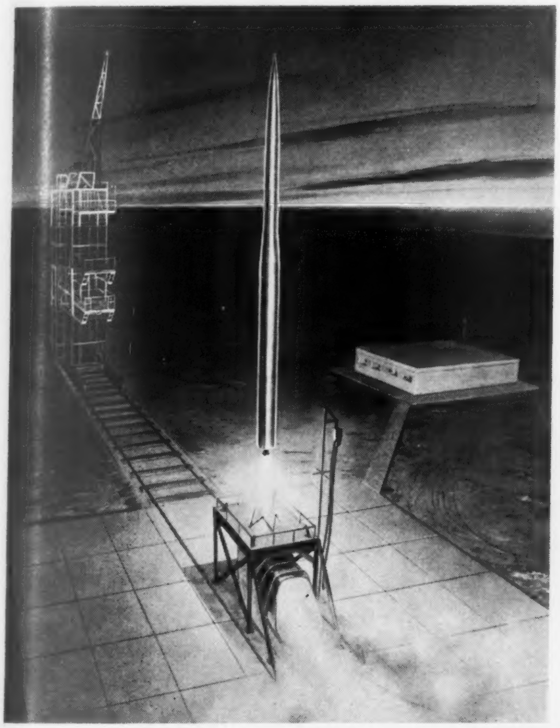
Jet Propulsion News

Alfred J. Zaehringer, American Rocket Company, *Associate Editor*
Norman L. Baker, Indiana Technical College, *Contributor*

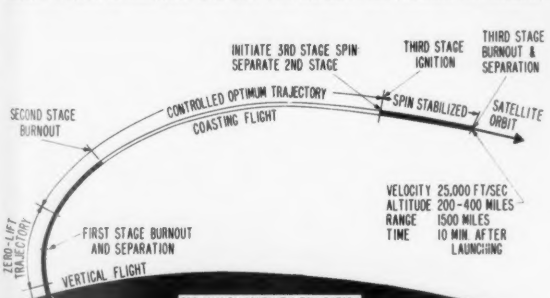
Rockets, Guided Missiles

PROJECT VANGUARD

STAGE 1 will resemble the VIKING and will be cylindrical without fins. Monocoque construction will be by Martin. General Electric will supply a regeneratively cooled rocket engine of about 27,000-lb thrust. Burning time may be 140 sec. The motor uses liquid oxygen as the oxidant while the fuel will be a mixture of ethanol, gasoline, and silicone oil. Hydrogen peroxide will drive turbopumps for propellant feed. Motor will be mounted on gimbals.



Artist's conception of the Martin Vanguard research vehicle which will place the world's first man-made satellite in its orbit around the earth. In background are the gantry used to place the vehicle on its launching stand, and the concrete blockhouse from which scientists will fire the rocket and record its course



Schematic of trajectory of Martin Vanguard research vehicle, depicting burnout positions of the three stages of vehicle in its flight to place a satellite in its orbital altitude of between 200 and 400 miles above the earth

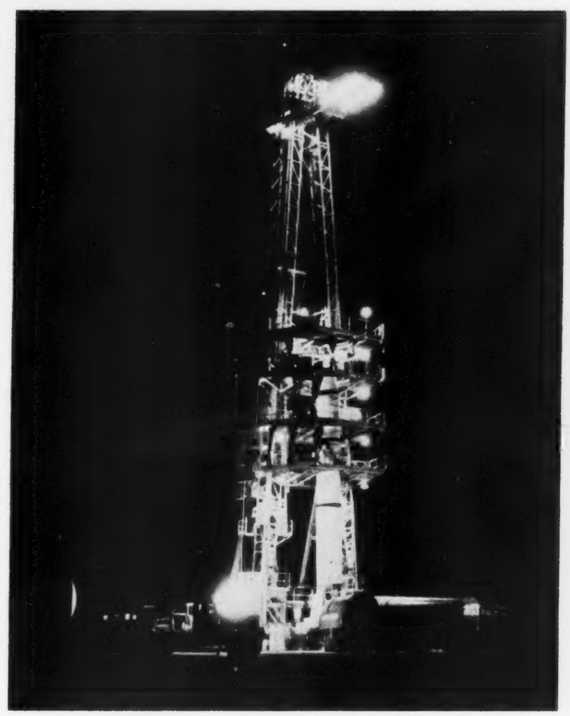
Stage 2 will be similar to the AEROBEE. Aerojet-General will build this stage, also of cylindrical construction and finless. This rocket motor also will be gimbal mounted; however it will burn nitric acid and unsymmetrical dimethyl hydrazine. Propellant feed will be by helium pressure.

Stage 3 may be a spin-stabilized solid propellant rocket. Grand Central and Hercules are the contractors.

Gross weight of the entire satellite vehicle may be about 20,000–25,000 lb. Over-all appearance will be long (50–75 ft) and slender (maximum diameter of about 36 in.). As yet, configuration details of the satellite itself have not been made known. In all probability it will be a small package weighing on the order of about 25 lb.

BALLISTIC MISSILES

REDSTONE surface-to-surface ballistic missile now has a range of 200–300 miles. The warhead apparently can be separated from the missile proper. The powerplant is a liquid propellant rocket engine by North American Aviation. The missile, developed by Army Ordnance at Redstone Arsenal, has been flight tested at Cocoa, Fla. (*photo*) and is ready for production at the Chrysler missile plant at Warren, Mich. Meanwhile, Chrysler has received a contract for an intermediate range ballistic missile (IRBM) with a range of 1000–1500 miles. This IRBM is intended for ship launching against surface targets. However, models for the Army are also reported in this joint Army-Navy project.



REDSTONE crews burn midnight oil at Patrick AFB, Fla. New gantry is of roll-away design

● Another IRBM program is being conducted by Douglas Aircraft for USAF. A British program under the aegis of Rolls Royce is also reported under way. The English firm is slated to use a North American Aviation rocket engine under license.

● The Army has announced the activation of the 217th Field Artillery Missile Battalion to be equipped with the REDSTONE missile. The unit is being formed at Redstone Arsenal.

● Reports indicate that the USSR has a 900-mile range ballistic missile and is very near the testing stage on a 1500-mile range IRBM. The Soviet ICBM program is also reported to be very active.

● A new project is said to be under way to develop an antimissile at North American Aviation. Meanwhile the Bell Telephone Laboratories has contracts to develop a missile which could intercept and destroy an ICBM.

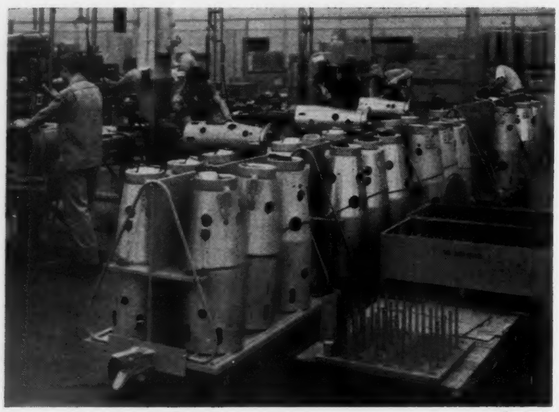
● Re-entry of intercontinental missiles to the atmosphere is the subject of a new $\$^1/_2$ million project under way at the NACA Ames Laboratory, Moffett Field, Calif.

● Bluff bodies (having highest drag to weight ratios) may be the solution to an ICBM return to the atmosphere at speeds of Mach 10–12, according to British scientists. Bluff bodies may be cooler than the fine aerodynamic shapes where laminar or turbulent boundary layer is concerned. Two promising shapes are the flat plate and the hemisphere-cylinder ("cannonball") combination. The latter appears to be preferable to ballistic (cone-cylinder) shapes because of its relatively low stagnation temperature and more efficient payload characteristics.

CRUISE MISSILES

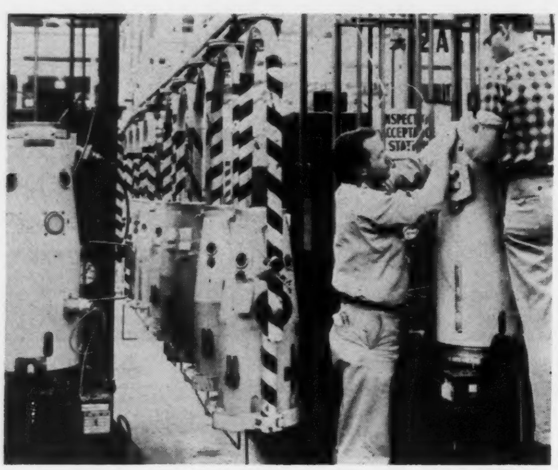
Wraps were finally taken away from the SNARK long-range cruise missile (*photo*). The Northrop missile is powered by a turbojet engine while launching boost is by rocket. Engine is aft with a long fuselage to provide fuel for intercontinental range (said to be 5000 miles). Also, tip tanks are slated to be attached to the swept wings.

Production Report



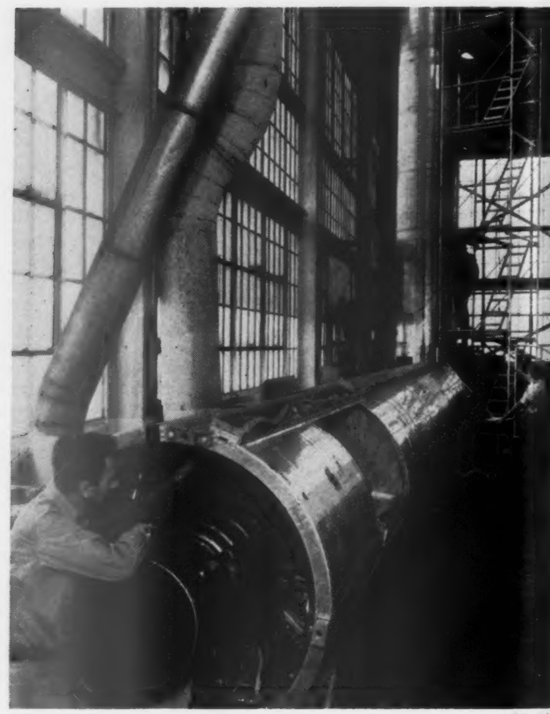
Convair

DRILLING . . . . Convair assemblymen drill reinforcing rings in aft guidance section (boat-tail) housing of Navy Terrier. This and next photo ("Checkout") were taken at the Navy Pomona, Calif., guided missile facility. The plant covers 17 acres and has over a half million sq ft of floor space. Included are an analogue computer, complete experimental factory, chemical and structural test labs. Additional structures include two drop towers and two 34-ft centrifuges



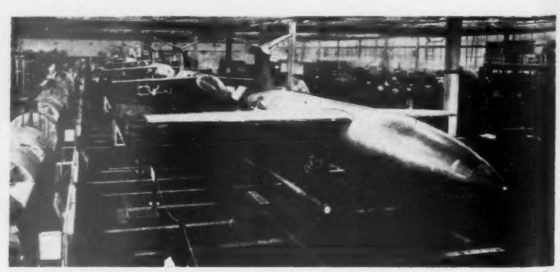
Convair

CHECKOUT . . . . Fixture at right simulates vibration and constitutes a final sectional checkout on the Terrier



Martin

UP AND DOWN . . . . Viking rockets get assembly checks in horizontal (foreground) and vertical (background) positions at Baltimore, Md., plant



Martin

MATADOR LINE . . . . USAF TM-61 is shown on the final assembly line at the Martin Baltimore, Md., plant

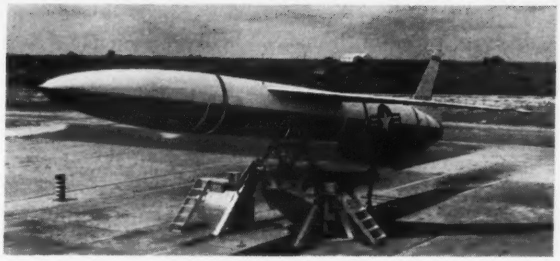
With MATADOR, TM-61, missiles rolling off the production lines in large numbers, additional details have been made by Martin and the Air Force. The TM-61 can fly faster than 650 mph and can reach altitudes of over 35,000 ft. The missile is powered by an Allison J33-A-37 turbojet engine while launching thrust comes from a T50 solid propellant booster. Martin started development in 1946 and the first production missile rolled off the line in June 1952. The missile is made in seven major, completely interchangeable sections. Much of the wing and tail is composed of aluminum honeycomb to which covering skin is bound by an adhesive material. Specifications include: length, 39.6 ft; diam, 54 in.; wingspan, 28.7 ft. Present models are already deployed in the shadow of the Iron Curtain (*photo*). New MATADOR models in test at Holloman AFB are called the TM-61B and sport a larger nose section and a new guidance system.

Douglas

BIRD LINE . . . . Nike comes down this overhead conveyor line at Douglas Aircraft, Santa Monica, Calif., production plant. Line is mechanized and some stages are automatic

Hughes

FALCON NESTED . . . . Falcon, GAR-1, guided missiles are nested in shipping boxes and on dollies before final acceptance by the Air Force. Production of the air-to-air missile is being made at Tucson, Ariz., plant of Hughes Aircraft Co.



First view of SNARK

MATADOR on alert

SURFACE-TO-AIR MISSILES

TALOS is a ramjet-propelled surface-to-air missile which is being produced by Bendix Aviation (prime contractor), McDonnell Aircraft (airframe) and Farnsworth Div. of IT&T (guidance). The missile has been assigned to both the Air Force and Navy, although a land version is being developed by RCA. The missile is accelerated by a solid propellant booster rocket. Speed of the ramjet is over Mach 2. The missile grew out of the 1944 Bumblebee project. In 1945, a static test of a 6-in. ramjet was begun by The Johns Hopkins University Applied Physics Laboratory. In 1946, an 18-in. ramjet was flown. TALOS bears a close resemblance to TERRIER. TALOS will be installed on the light cruiser *USS Galveston*. Other light cruisers will also have TALOS batteries.

● TARTAR missile is being developed by Convair as a replacement for 5-in. naval gun batteries.

● The cruisers, *USS Boston*, *Northampton*, and possibly the *Canberra* will form the backbone of the Navy's guided missile division. The Boston recently fired TERRIER missiles against target planes. Hits were recorded at a range of 6 miles and an altitude of 15,000 ft.

● BOMARC, long-range interceptor missile, is now in the "prepare for production" stage.

● Since NIKE crews are on a 24-hr alert maintained seven days a week, $8 million has been released for permanant housing. Funds will be enough for 600 of the 910 units authorized.

AIR-TO-AIR MISSILES

SIDEWINDER missile, now being produced by Philco, is to be produced for the Navy Bureau of Ordnance by General Electric.

● CROSSBOW missile is being produced by Radioplane, a division of Northrop.

● Long-range GOOSE missile is being developed by Fairchild for USAF.

• DING DONG is a new missile which is under development by Douglas Aircraft with guidance by Hughes Aircraft. Nuclear warhead of the missile has been tested in Nevada at 30,000 ft. The missile uses a rocket engine by North American. TINGALING is a ballistic spotting version of the DING DONG nuclear missile.

• Reliability of liquid propellant rocket engines is now near 100 per cent according to the Air Force. Solid propellant reliability is even higher; since 1945 several thousand RATO's have been fired and only ten failures were reported—one of these resulting in a fatality. It is presumed that the statements apply only to operational units.

• X-15 is the designation for the new North American Aviation rocket plane under development.

• The heavy cruiser, *USS Macon*, has been modified to carry and launch the REGULUS missile. Winter training was scheduled for the missile cruiser at Guantanamo Bay, Cuba.

• FIREBEE missiles will be delivered to the Air Force and Navy in a new $4 million contract.

• The USAF missile range now is instrumented with 21 radar tracking stations. The 1600-mile range extends from Cape Canaveral, Fla., to St. Lucia Island. The radar net was an expenditure of $10 million with central control at Patrick AFB. Reeves Instrument designed and bulit 16 stations on 8 major islands plus 5 mobile installations. Accuracy of the system is claimed to be ± 0.02 deg in position.

• British plants producing missiles soon to enter the production phase are Armstrong-Whitworth, Bristol, de Havilland, English Electric, Fairey, and Vickers-Armstrong. RAF personnel are being familiarized with the new guided missiles soon to become operational.

• New British solid propellant research rocket has a diameter of 17 in. and is about 25 ft long. Design altitude is 120 miles. Developed at the Farnborough Royal Aircraft Establishment, the rocket uses a low burning rate grain.

• SPARROW will be manufactured in Canada by A. V. Roe (administrative), Canadair (airframe), and Canadian Westinghouse (guidance). Powerplant resumably will come from the USA. Canada has dropped its VELVET GLOVE project in favor of SPARROW.

• FALCON, GAR-1, rockets are now being carried on the Scorpion interceptor. The F-89H is now in quantity production and several wings of the Scorpion-FALCON team are already in operation. Three GAR-1's are carried in each wingtip pod. Mighty Mouse rockets will also be carried.

MISSILE-ANIA

Missile funds for fiscal year 1956 will be $0.97 billion while FY1957 will hit $1.3 billion. About $250 million will go for research and development. R&D breakdown is: Air Force, $100 million; Army, $75 million; Navy, $75 million.

• The Defense Department has approved a $15.31 million expenditure for a classified project at Holloman AFB, N. Mex. Another outlay, $7.877 million, was also recently awarded this ARDC base for research, development, and housing.

• A combination DEACON and LOKI (both solid propellant rockets) was recently fired by the Navy in Arctic tests.

• In unmanned tests, the Northrop rocket sled at Edwards AFB, Calif., hit a speed of 995 mph. An additional 1500 ft to the present track of 3500 ft will allow new sleds to hit 1300 mph.

• On-off solid propellant rocket motors have been reported. Technique is to vent combustion gases through an auxiliary nozzle. The pressure then drops to a point where combustion ceases.

• Marcel-Dassault MD-550, delta wing interceptor is powered by a SEPR rocket engine which is expected to push the plane to a speed of Mach 1.7.

• The West German Army will soon have a rocket arm. Ground-to-ground and ground-to-air missiles will be tested. The special 600-man unit will be stationed on the North Sea coast in Germany.

• In 1954 the Research Institute for the Physics of Jet Propulsion was formed at the Stuttgart Airport, Germany. Founding members are the following groups: R. Bosch, GmbH (Stuttgart); Brown, Boveri et Cie AG (Mannheim); Daimler-Benz AG (Stuttgart); German Propeller Study Society (Stuttgart); Dornier Werke GmbH (Friedrichshafen); Society for Space Research (Stuttgart); E. Heinkel AG (Stuttgart); and F. Porsche K.G. (Stuttgart). The main line of work of the institute is fundamental and applied research in the transition range between aeronautics and astronautics. Typical fields are: theory of jets and rockets, physics of combustion, gas radiation, physics of wall effects. Among the notable scientists in the group is Eugen Saenger.

Liquid Propellant Progress

AEROJET-GENERAL CORP. of Azusa, Calif., investigated the combustion of WFNA and hydrocarbons. They found longitudinal stratification of composition and temperature. The NO/N_2 ratio is a parameter of combustion completeness. Injector design was found to have little effect on the chemistry of the combustion process.

• Allegany Ballistics Laboratory, Cumberland, Md., surveyed the combustion of nitrate esters. Methyl nitrate was among them. It was concluded that the combustion zone is about 1 magnitude thinner than hydrocarbon flames.

• Armour Research Foundation, Chicago, Ill., has produced 100 per cent liquid ozone (LOZ). Process consists of purifying oxygen (OX). Organic impurities must be kept below 20 ppm for stable LOZ. Process feeds very pure OX into ozone (OZ) generator. Mixture of OZ (1–6 per cent) and unconverted OX are refrigerated; OZ results at -111.9 C at 1 atm. Using spark initiation, OX-OZ (38 per cent vol OZ) mixtures detonate with 0.00001 cal ignition energy producing decomposition waves of 24,000 cm/sec. Velocities of 215,000 cm/sec have been noted in violent detonations.

• Becco Chemical Division, Buffalo, N. Y., reports that it is now prepared to make hydrogen peroxide in concentrations between 90–100 per cent. Using fractional crystallization the process allows reagent grade purity. The company has been producing 90 per cent peroxide for 10 years.

• General Electric Co., Schenectady, N. Y., found that silicon tetrafluoride reacts with hydrogen at over 2000 C with the formation of fluosilanes and hydrogen fluoride. Reactions were carried out by heated filaments or electric arcs.

• Rohm & Haas, Redstone Arsenal Research Division, Huntsville, Ala., studied the decomposition of nitroethane, 1-nitropropane, and 2-nitropropane. Decompositions were all first order. Activation energies ranged from 39 to 47 kcal/mole.

• Linde Air Products Co., Tonawanda, N. Y., also was concerned with ozone. They concluded that even the highest purity OZ occasionally detonates and no positive way of preventing detonations has yet been found. It is also felt that much work will have to be done on liquefying, concentrating, and handling OZ before it can be safely handled and used to propel large rockets.

• Purdue University, Lafayette, Ind., used RFNA and WFNA to study heat transfer of these materials in regeneratively cooled rockets. Heat flux (B/sec sq in.) ranged from 0.86–5.13 for WFNA and 0.34–1.88 for RFNA. Inlet pressure of WFNA had no effect on heat transfer. Scale formation was serious in longer runs.

Space Flight Notes

Kurt R. Stehling, Naval Research Laboratory, Contributor

Recovery of a Satellite Vehicle[1]

IT has been widely assumed, in unclassified discussions on the lifetime and orbit of a small satellite vehicle, that this vehicle would have a limited lifetime in the orbit and would terminate its brief career in a meteorlike disintegration or vaporization on re-entry in the atmosphere.

Even a casual examination of the re-entry problem shows that the aerodynamic heating suffered by a vehicle in the atmosphere traveling at 5 mps would result in a very severe temperature rise which would tend to melt or vaporize the structure. The authors have discussed this re-entry problem based on simple fundamental principles and have shown one method of protecting a re-entering vehicle from the expected rapid and great temperature rise.

Meteors are described as typical and fairly well understood examples of bodies which enter the atmosphere at very high speeds. Many millions of these meteors bombard the earth each day at velocities often greater than 20 mps. Most of them vaporize or disintegrate in a region from 60 miles to 100 miles altitude.

The case of a re-entering satellite is then considered with the vehicle plunging into the atmosphere at 4 mps from 100 miles altitude. Several simplifying assumptions were made which were not considered prejudicial to the main thesis of re-entry.

(a) The vehicle, weighing 100 lb, turns suddenly downward at 100 miles and 4 mps and enters the atmosphere vertically.

(b) All the kinetic and potential energies of the vehicle must be dissipated by the time the vehicle reaches the earth's surface. It is arbitrarily assumed that one half of this energy is transferred to the surrounding atmosphere and that one half must be absorbed by the vehicle. This assumption on heat balance may be reasonable if a laminar boundary layer in the viscous flow domain is considered. L. Crocco[2] has found that for a particular value of the ratio between the coefficients of heat conduction and viscosity, corresponding to a Prandtl number equal to 1, an equal heat balance between the air and the re-entering body (in this case) is obtained. This heat balance is complete in the sense that the sum of the enthalpy and the kinetic energy of the unit mass are constant across the boundary layer.

(c) The rate of heat generation is distributed uniformly over the descent path.

(d) After the vehicle reaches Mach 5 or 1 mps, the stagnation temperature would be less than 2000 deg F, which is assumed less than the melting point of the metal shell. Therefore, from this point on the vehicle would suffer a cooling rather than a heating cycle.

(e) The aerodynamic forces do not weaken or destroy the structure. Also, the protective nosepiece or film will maintain its integrity through the descent.

(f) Most of the heating occurs on the frontal region of the vehicle (this assumption is noted only as a matter of interest and does not affect the treatment of the problem).

It is shown that the total energy which is generated by the vehicle is equal to the sum of the change of kinetic and potential energy existing at the initial stage of desent and the condition existing at the earth. This sum is 9880 Btu /lb of structure, or 988,000 Btu for the 100-lb vehicle of which one half, or 494,000 Btu, must be absorbed. With an assumed descent time of 40 sec and frontal area of 1 ft squared, the heat transfer rate is approximately 12,300 Btu/sec corresponding to a heat flux of 86 Btu/sq. in.-sec.

The authors suggest that the sublimation of some material, such as a refractory, might absorb this high rate of heat input. Beryllia (BeO) is the substance selected; its sublimation absorbs 10,600 Btu/lb at a temperature of 4500 deg F. Therefore, for the vehicle considered, a nose cone of 46.5 lb of beryllia would suffice to absorb the energy of re-entry. The low thermal conductivity of the beryllia results in a temperature rise of only 1000 deg F at the metal-ceramic interface in 40 sec, with a $^1/_4$-in. thick layer of ceramic.

The lifetime of an atmosphere re-entering satellite is surely not an academic consideration but is of very real importance to the scientist who is concerned with either the complete destruction of the vehicle lest it fall into an inhabited area or, alternately, with its deliberate recovery, intact, for recovery of recorded data.

The authors have assumed the latter premise; however, they have dealt with the problem in its most elementary form. Such factors as the nature of the gaseous environment (i.e., whether discrete particle, slip, or free stream flow are extant) and radiations from the vehicle have not been considered. Whether the latter process and the transmission of wave energy to the atmosphere can account for one half of the generated energy is not proved.

The 40-sec vertical descent path is also a very drastic re-entry condition. It is much more likely that the vehicle will re-enter in a long spiral. If its transit time to earth took, say, 400 sec, then the heat flux would be reduced to an average of 8.6 Btu/sq in.-sec—a value not uncommon for rocket chambers or high temperature electric arc furnaces.

The structural stability under severe aerodynamic loads of a resistive coating or indeed of the vehicle itself cannot be lightly glossed over as was done by the authors. For instance, if a plastic or ceramic film were used, the former could slough off as fast as a liquid film were formed, while the latter could crack or crumble under the severe bending loads caused by the aerodynamic forces.

However, the paper has shown that the heat energy generated by a satellite plunging through the atmosphere can be absorbed by some type of coating—here, a ceramic. Other materials could be used; in fact, the supporting nonpayload structure of a satellite could serve such a function.

[1] Based on a paper by T. F. Reinhardt, Kurt R. Stehling, and Leo Dean, of Bell Aircraft, Naval Research Lab., and Aerojet-General, respectively.

[2] Crocco, L., "Lo strato limite laminare nei gas," *Monografie Scientifiche di Aeronautica* no. 3, 1946.

Facts on Vanguard

1. The vehicle will be launched from Patrick Air Force Base, Cocoa, Fla.

2. In cooperation with the U. S. National Committee for the IGY, the Defense Department part of the project is shared by the three military services under Navy management.

3. The vehicle consists of three stages: (a) Stage 1— Powered by a General Electric turbopump rocket engine of 27,000-lb minimum thrust, burning liquid oxygen and a mixture of gasoline, silicone oil, and ethyl alcohol, for about 140 sec. (b) Stage 2— The Aerojet-General Corporation, Azusa, Calif., is building the pressure-fed rocket thrust chamber, which burns fuming nitric acid and unsymmetrical dimethyl hydrazine. (c) Stage 3— This stage consists of a solid propellant rocket which will propel the satellite itself into the orbit.

4. The first stage, Stage I, will separate from Stage II and Stage III after having brought the whole vehicle to a velocity of 3000–4000 mph, about 40 miles from the launching site.

The second stage, on burnout, will have attained a velocity

of about 11,000 mph, at an altitude of about 130 miles. It will then coast on upwards to about 300 miles.

The third stage will then separate and continue in the orbit, with a burnout velocity of 18,000 mph.

5. The satellite itself will be a sphere, weighing approximately $21^1/_2$ lb and approximately 20 in. in diam. It will contain instrumentation for recording various scientific events. It will also house a small tracking radio transmitter which will permit a Naval Research Laboratory developed tracking system (Minitrack) to locate and follow the satellite—aside from any optical observations which may be made.

6. The launching vehicle will have no fins, but will depend on the gimballed rocket engine and auxiliary control jets for altitude and directional control.

7. A series of test vehicles will be fired first in order to establish the function and reliability of the components.

8. The initial angle between the vehicle flight path and the equator will be approximately 40 deg. This figure may change slightly with succeeding revolutions because of various perturbations on the satellite by the oblate shape of the earth.

Radio Astronomy

The detection and measurement of celestial microwave sources has proved a powerful supplement to optical astronomy utilizing visible, ultraviolet, and infrared light.

The discovery of radio waves of extraterrestrial origin was made by Karl G. Jansky[3] in 1932 while studying the direction of atmospheric static at a wavelength of 14.6 meters.[4] He noticed a very steady weak hissing static of unknown origin, whose direction of arrival changed gradually, going around the compass in about 24 hr. Further study revealed that the maximum intensity peaks were recorded when the plane of the Milky Way was in the antenna beam.

In 1946, shortly after World War II and partly as a result of the advances in microwave and radar techniques which resulted from this conflict, research in radio astronomy (the name for this new science was then coined) was intensified. The British and Australians led the field, although important contributions began to be made by American and other workers.

Radio stars have now been found in great numbers, almost exclusively at meter wavelengths. (The only exceptions are a few at 9.4 centimeters, Fig. 1, and five sources at 25 centimeters wavelength). The reason for this is twofold: (a) The intensity of all radio stars which had been measured at several frequencies showed a steady decrease in emission with decreasing wavelength; and (b) it is more difficult and expensive to build antennas of great effective area for shorter waves since design tolerances are proportional to wavelength. The lack of directivity at long wavelengths was largely overcome by interferometric methods of reception.

The British have built the Jodrell Bank Experimental Station at the University of Manchester. This may be regarded as the world's largest radio telescope—a paraboloidal steel reflector, 250 ft in diam and 62.5 ft deep at the center. The reflector weighs 600 tons.

Recent news releases state that the U. S. Congress has been approached for funds to build a very large paraboloidal radio telescope (140 ft diam) in this country, with a later model to follow having a diameter of perhaps 600 ft. These paraboloidal reflectors can be moved in azimuth or on a polar axis to follow celestial radio sources, just as an astronomical telescope can, Fig. 2.

Another type, the "meridian transit" telescope, is planned for Ohio State University, paid for by a grant by the National Science Foundation, and will operate on wavelengths of 1 meter or less. This instrument will be the world's largest; however, it will only be able to receive along a North-South line, scanning in an East-West direction through the earth's rotation. It will also be able to receive some off-axis signals which will broaden its normal field of view.

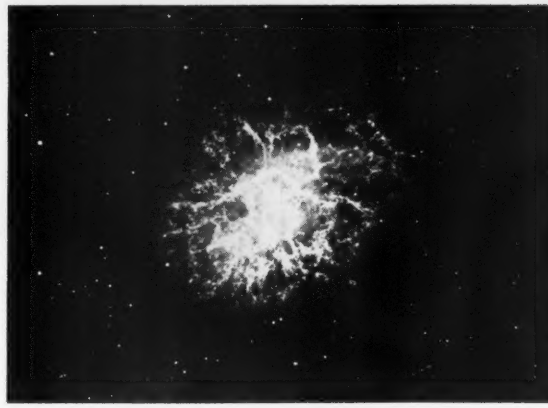


Fig. 1 The first known radio star—the Crab Nebula in Taurus

This object was the first radio star to be identified with an optically known object by the Australians in 1949. It is the gaseous remains of one of the three supernova seen in our galaxy in recent history. The nebula is expanding 1200 km/sec. It is 3300 light years distant and has been observed at 9.4 centimeters.

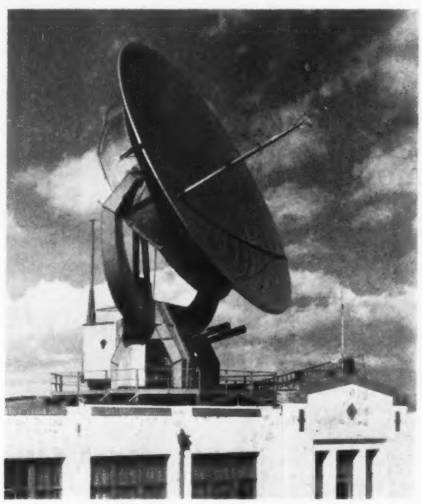


Fig. 2 The Naval Research Laboratory's paraboloidal radio telescope

This 50-ft-diam f/0.5 reflector is one of the most powerful instruments in the country, with an antenna gain of over a million. Its surface is accurate to $\pm ^1/_{32}$ in. The disk consists of 30 castings weighing 1000 lb each, rigidly bolted together. The yoke and Naval gun mount and the disk weigh over 50 tons. At 3 cm wavelength it has a beam width of 0.15 deg. It is making significant contributions to the store of data on the energy spectrum of various radio-emissive stars. It is also used for radio intensity distribution measurements over the solar disk. At 8 mm wavelength it will be possible to detect thermal emission from Venus and Jupiter. Lunar measurements include study of temperature variations of moon's crust during lunar day and radar distance measurements at 10 cm and 3 cm wave-lengths.

Radio astronomy is now an important segment of the cosmological sciences. It is another approach to the method of measuring and evaluating the physical processes extant in space and the sun and the stars. However, the techniques developed and the data gained not only contribute to astrophysics but will build up a great body of experience for that time when tracking and communication in space for and between space vehicles will be a reality.

[3] Bell Telephone Laboratories.

[4] *Proceedings of the Institute of Radio Engineers*, vol. 20, 1932, p. 1920.

ARS News

Ramjets, Propellants, Satellites Highlight Cleveland Program, June 18-20

Murphree, missile "czar," to speak at Semi-Annual Meeting banquet

An ARS committee headed by Case Institute of Technology's Henry Burlage, Jr., has come up with what promises to be one of the Society's outstanding technical programs.

Four sessions—on ramjets, liquid propellants, solid propellants, and satellites—will see fifteen papers presented at the Society's June 18–20 meeting at the Hotel Statler in Cleveland. The program will be conducted in conjunction with the Semi-Annual Meeting of The American Society of Mechanical Engineers.

Host for the ARS portion of the meeting will be the Cleveland-Akron Section. The Section's President, W. T. Olson, Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics, will be toastmaster at a banquet to be held on Monday evening, June 18. The speaker for this affair will be Eger V. Murphree, Special Assistant to Secretary of Defense for guided missiles.

Paul Ordin, also of NACA, Arrangements Chairman, announces that a program of special events has been arranged by the Cleveland ASME-ARS committee which will include a showing of the musical, "King and I," on Sunday evening, June 17; a baseball game between Boston Red Sox and Cleveland Indians on Tuesday evening, June 19, and a trip to the Lewis Lab on Wednesday afternoon, June 20.

Sessions of possible interest to ARS members are also being conducted by ASME's Heat Transfer, Gas Turbine Power, and Aviation Divisions, June 18–21.

The complete program is as follows:

SUNDAY, JUNE 17

2:00 p.m. Registration

8:30 p.m. "The King and I"
Musicarnival
Warrensville Heights, Ohio
(Transportation from Hotel Statler furnished)

MONDAY, JUNE 18

8:00 a.m. Registration

9:30 a.m. Ramjets

Chairman: James W. Useller, NACA, Cleveland, Ohio

The Ramprop, A Supersonic Jet-Driven Propeller, by Albert Gail, Cornell Aeronautical Lab., Buffalo, N. Y. (296-56)

The LeDuc 022 Ramjet Airplane, by Rene LeDuc, LeDuc et Fils, France (297-56)

Some Fundamental Aspects of Ramjet Propulsion, by Arthur N. Thomas, Jr., Marquardt Aircraft Co., Van Nuys, Calif. (298-56)

9:30 a.m. ASME Heat Transfer I
Gas Turbine Power I

Chairman: Sigmund Kopp, Alco Products, Inc., Dunkirk, N. Y.

Vice-Chairman: R. L. Lyerly, Cornell Aeronautical Lab, Buffalo, N. Y.

Generalized Optimal Heat Exchanger Design, by David H. Fax, Atomic Power Div., Westinghouse Electric Corp., Pittsburgh, Pa. (ASME 56-SA-19)

Tests of Free Convection in a Partially Enclosed Space Between Two Heated Vertical Plates, by R. Siegel, NACA, Lewis Lab, Cleveland, and R. H. Norris, General Electric Co., Schenectady, N. Y.

2:30 p.m. Liquid Propellant Rockets

Chairman: John Slopp, NACA, Cleveland, Ohio

Dynamics of a Pump-Fed, Variable-Thrust, Bi-Propellant, Liquid Rocket Engine System, by Marvin R. Gore and John J. Carroll, Aerojet-General Corp., Azusa, Calif. (299-56)

Hydrogen Peroxide Oxidant for Aircraft Propulsion, by Andrew J. Kubica and James C. McCormick, Becco Chemical Division, Food Machinery and Chemical Corp., Buffalo, N. Y. (300-56)

Solid-Liquid Rocket Propellant Systems, by George E. Moore and Kurt Berman, General Electric Co., Cincinnati, Ohio (301-56)

An Evaluation of Various Liquid Rocket Exhaust Jet Flame Suppressants, by John C. Becker, Jr., Aerojet-General Corp., Azusa, Calif. (302-56)

2:30 p.m. ASME Heat Transfer II

Chairman: G. M. Dusinberre, Penn State University, University Park, Pa.

Vice-Chairman: W. L. Ryan, Case Inst. of Tech., Cleveland, Ohio

A Novel Method of Obtaining an Isothermal Surface for Steady State and Transient Conditions, by G. N. Hatsopoulos and J. Kaye, Mass. Inst. of Tech., Cambridge, Mass. (ASME 56-SA-13)

A Mechanical Computing Device for One-Dimensional Transient Heat Conduction Problems, by W. E. Rowland, E. A. Trabant, and G. A. Hawkins, Purdue University, Lafayette, Ind.

Study of Heat Transfer to Liquid Nitrogen, by Leo M. Thompson, Bell Aircraft Corp., Buffalo, N. Y. (ASME 56-SA-4)

7:00 p.m. ARS Banquet

Toastmaster: W. T. Olson, President, Cleveland-Akron Section

Speaker: Eger V. Murphree, Special Assistant to Secretary of Defense for guided misssiles

TUESDAY, JUNE 19

8:00 a.m. Registration

9:30 a.m. Solid Propellant Rockets

Chairman: A. L. Antonio, General Tire and Rubber Co., Akron, Ohio

Importance of Mass Ratio and Adaptability of Case Bonded Solid Propellant Rocket Systems for Achievement of Super Velocities, by J. W. Wiggins, Thiokol Chemical Corp., Huntsville, Ala. (303-56)

Cold Forming Methods for Fabrication of Inert Rocket Components During Development, by H. R. Grant, Aerojet-General Corp., Azusa, Calif. (304-56)

Range, Burnout Velocity, and Design of Solid Propellant Rocket Ballistic Vehicles, by P. J. Blata and R. D. Geckler, Aerojet-General Corp., Azusa, Calif. (305-56)

9:30 a.m. ASME Heat Transfer III
Aviation I

Chairman: Victor Kropf, Westinghouse Electric Corp., Pittsburgh, Pa.

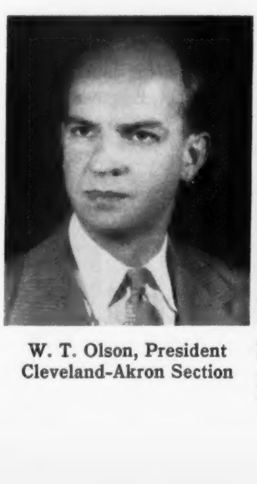
Vice-Chairman: Frank Rom, NACA, Lewis Flight Propulsion Lab, Cleveland

Thermal Problems of High Speed Flight and the General Electric Aircraft Cooling Program, by J. W. Rizika, General Electric, West Lynn, Mass. (ASME 56-SA-24)

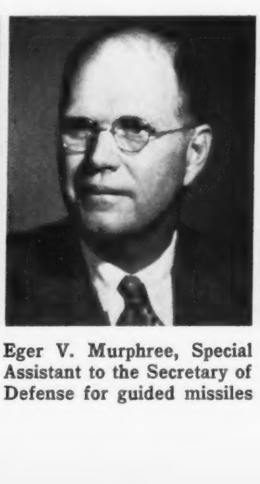
A Survey of Possible Refrigerants for High Temperature Application, by Jon Van Winkle, General Electric Co., Pittsfield, Mass. (ASME 56-SA-12)

A Comparison of Refrigerants When Used in Vapor Compression Cycles Over an Extended Temperature Range, by J. P. Barger, W. M. Rohsenow, and K. M. Treadwell, Mass. Inst. of Tech., Cambridge, Mass. (ASME 56-SA-6)

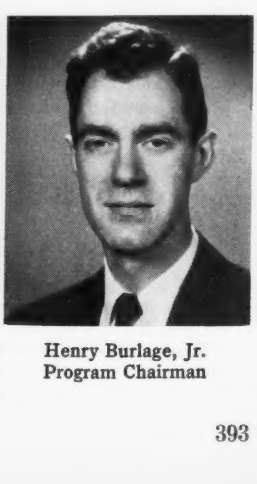
Turboconditioning Systems with Vapor Compression Cycles, by J. P. Barger, W. M. Rohsenow, and K. M. Treadwell, Mass. Inst. of Tech., Cambridge, Mass. (ASME 56-SA-7)



W. T. Olson, President Cleveland-Akron Section



Eger V. Murphree, Special Assistant to the Secretary of Defense for guided missiles



Henry Burlage, Jr. Program Chairman

2:30 p.m. Satellite Flight

Chairman: D. C. Romick, Goodyear Aircraft Corp., Akron, Ohio

Instrumentation Problems of Medium-Size Satellites, by Ernst Stuhlinger, Redstone Arsenal, Huntsville, Ala. (306-56)

The Effect of Meteoric Particles on a Satellite, by S. F. Singer, University of Maryland, College Park, Md. (307-56)

Azusa, Calif. (308-56)
by Irvine G. Henry, Aerojet-General Corp.,
Lifetime of Artificial Satellites of the Earth,

Satellite Communication Problems, by J. Jensen, Glenn L. Martin Co., Baltimore, Md. (309-56)

The Solar-Powered Space Ship, by Krafft A. Ehricke, Convair, San Diego, Calif. (310-56)

2:30 p.m. ASME Heat Transver IV Aviation II

Chairman: Simon Ostrach, NACA, Cleveland

Vice-Chairman: Stephen Maslen, NACA, Cleveland

Influence of Through Metal on Heat Transfer Through Aircraft Structure Sandwich Panels, by J. R. Woolf and L. R. Scott, Jr., Convair, Fort Worth, Texas

A Systematic Study of Air Cycles for Aircraft Cooling Applications, by L. R. Stevens, Jr., General Electric Co., West Lynn, Mass. (ASME 56-SA-11)

5:45 p.m. ASME Baseball Night

Roast Beef Buffet Dinner in outfield of Municipal Stadium. Meet ball players and see Cleveland Indians-Boston Red Sox game. (Transportation from hotel)

WEDNESDAY, JUNE 20

9:30 a.m. Aviation III New National Facilities for Propulsion Research and Development

Chairman: Abe Silverstein, NACA, Cleveland, Ohio

Vice-Chairman: W. R. New, Westinghouse Electric, Kansas City, Mo.

Propulsion Facilities at Trenton, by Lester G. Tilton, Naval Air Turbine Test Station, Trenton, N. J.

Propulsion Facilities at the Arnold Engineering Development Center, by John M. Wild, Aro, Inc., Tullahoma, Tenn.

Propulsion Wind Tunnels at Lewis Flight Propulsion Lab, by E. W. Wasielewski, NACA, Cleveland

1:30 p.m. Inspection Trip

Lewis Flight Propulsion Lab, NACA. Visitors will see supersonic wind tunnels, altitude chambers for testing turbojets and ramjets over a broad range of Mach numbers and altitudes, the Rocket Lab, and other facilities.

2:30 p.m. ASME Gas Turbine Power IV Power V

Problems Encountered in the Translation of Compressor Performance from One Gas to Another, by Melvin J. Hartmann and Ward W. Wilcox, NACA, Cleveland

Facilities and Instrumentation for Compressor and Turbine Research at the NACA Lewis Flight Propulsion Lab, by Arthur A. Medeiros and Channing C. Conger, NACA, Cleveland.

THURSDAY, JUNE 21

9:30 a.m. ASME Gas Turbine Power IV

Research on Application of Cooling to Gas Turbines, by Jack B. Esgar, John B. Livingood and Robert O. Hickel, NACA, Cleveland

Considerations in the Development of Small Turbojet Engines, by Donald J. Todd and Leonard F. Westra, Continental Aviation and Engineering Corp., Detroit, Mich.

Haley, Program Chairman, Invites Papers for Forthcoming Meetings

ANDREW G. HALEY, National ARS Program Chairman, announces that papers are invited for forthcoming national meetings. Papers should conform to specifications listed on page 321. Details on subjects to be covered are:

September 17–21

Seventh Annual Congress, International Astronautical Federation, Rome—On space flight, rocket propulsion, satellites, upper atmosphere research, trajectories and orbits, space vehicle design, space navigation, space medicine.

Submit papers to:

Andrew G. Haley, Program Chairman
American Rocket Society
1735 DeSales Street
Washington, D. C.

Deadline for manuscripts: June 30.

September 24–26

ARS Fall Meeting, Hotel Statler, Buffalo, N. Y.—On combustion, instrumentation,

liquid propellants, rocket installations problems, test facilities, manufacturing problems, education.

Submit papers to:

Ralph H. Bloom, Program Chairman
ARS Fall Meeting
Becco Chemical Division
Food Machinery and Chemical Corp.
Buffalo 7, N. Y.

Deadline for manuscripts: June 15.

November 25–30

ARS Annual Meeting, New York—On space flight, guided missiles, rockets, ramjets, instrumentation, guidance and control, fuels and combustion, nuclear propulsion, satellites.

Submit papers to:

Andrew G. Haley, Program Chairman
American Rocket Society
1735 DeSales Street
Washington, D. C.

Deadline for abstracts: June 15.
Deadline for manuscripts: August 27.

Cowen Announces Competition For ARS Student Award

J. B. COWEN, Chairman of the 1956 Awards Committee, has established a deadline date of August 15, 1956 for entries in this year's ARS Student Award competition.

Papers may deal with any subject within the scope of ARS interest—rockets, ramjets, space flight, combustion—and will be judged on the basis of accuracy, expression, understanding of the subject, and originality of thought.

A medal will be awarded to the winner at the Annual Meeting Banquet in New York in November.

Send entries to:

J. B. Cowen, Chairman
Awards Committee
American Rocket Society
Aerojet-General Corporation
1625 Eye Street, N. W.
Washington, D. C.

Aerial view of Canadair Ltd., Montreal, which will be visited by delegates to the convention. Canadair produces F-86 Sabres, T-33 Silver Star jet trainers, CL-28 maritime reconnaissance aircraft, and is engaged in guided missile and nuclear work

ARS to Participate in Montreal Meeting

A PAPER on the earth satellite program by Rear Admiral F. R. Furth, USN (Ret.), will be sponsored by ARS at the 70th Annual General and Professional Meeting of the Engineering Institute of Canada. Also co-sponsoring the meeting, which will take place May 23–25 at the Sheraton-Mount Royal Hotel, Montreal, is The American Society of Mechanical Engineers.

A feature of the meeting will be a plant visit and air show to be staged by Canadair Ltd. (*photo*).

The portion of the program of interest to ARS members is as follows:

Thursday, May 24

9:00 a.m. The Metal Bonding of Aircraft Assemblies, by J. J. Waller, Canadair, Ltd., Montreal.

10:00 a.m. The Challenge of Progress, by R. C. Sebold, Convair, San Diego, Calif.

11:00 a.m. Project Vanguard—The IGY Earth Satellite, by F. R. Furth, Farnsworth Electronics, Fort Wayne, Ind.

2:00 p.m. Canadair Visit and Air Show, Cartierville, P. Q.

Helping Make Naval History

Terrier-Armed Cruiser to Defend Navy's Atlantic Fleet Task Forces

BY DAVID A. ANDERTON

Aviation Week, November 7, 1955.—Operational integration of the Navy's first guided missile cruiser—the USS *Boston* (CAG-1)—will begin early next year when the converted ship joins the Atlantic Fleet.

The *Boston* is armed with two twin launchers firing the supersonic Convair Terrier anti-aircraft missile. Fleet operations with the Terrier follow extensive test firings of the missile, including a series from the Atlantic Fleet's experimental gunnery ship, the USS *Mississippi*.

TERRIER HISTORY

The Terrier is the first weapons system to come from the Bureau of Ordnance's ten-year-old Section "T" contract with the Applied Physics Laboratory of Johns Hopkins University. Prompted by Japanese Kamikaze attacks in the closing months of World War II, the bureau established the missile research and development project under the code name of Bumblebee.

Scientists of JHU/APL made initial studies that led to the Terrier; other phases of the Bumblebee program have produced Talos, another anti-aircraft missile with ramjet propulsion, and the Triton.

As Terrier tests made the missile look more and more promising, the Navy opened a new production plant at Pomona, Calif., and turned the operation of the facility over to the Convair Division of General Dynamics. Production began in January 1953.

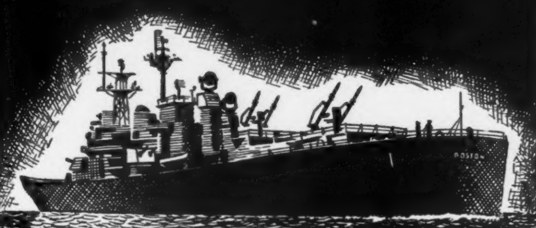
MISSILE DIVISION

The powerplant, a sustainer rocket built by the M. W. Kellogg Co., occupies the bay between the wings and the tail. The aft guidance section mounts the fins, antennas and related avionic gear.

Convair produces both guidance sections, the spines connecting those sections, and all the aerodynamic surfaces.

The *Boston*, as the first guided-missile cruiser, forms the nucleus of the Navy's first guided-missile division.

In addition to actually building the Terrier's powerplant, as mentioned in this "Aviation Week" article, The M. W. Kellogg Company also participated in the initial conception of the Terrier's propulsion system and in the ultimate development of this guided missile as one of the Navy's primary anti-aircraft weapons. To date, M. W. Kellogg's unique industrial background in the utilization and control of high temperatures and pressures has contributed to the engineering and production of over ten different rocket engines for the Armed Forces.



PROCESS EQUIPMENT

PETROLEUM REFINERIES

CHEMICAL PLANTS

CHEMICAL MATERIALS

SPECIAL STEEL ALLOYS

POWER PIPING AND CHIMNEYS

M.W. Kellogg

ENGINEERING FOR TOMORROW

THE M. W. KELLOGG COMPANY, NEW YORK 17, N. Y.

The Canadian Kellogg Company, Limited, Toronto • Kellogg International Corporation, London.

SUBSIDIARIES OF PULLMAN INCORPORATED

Sacramento Section Officers Elected

THREE successful dinner meetings were held this year in establishing the Sacramento Section. The following officers were elected: President, Frank Coss; Vice-President, Daniel M. Tenenbaum; Treasurer, Raymond C. Stiff; Secretary, Wayne H. Fenton; Assistant Secretary, William Rideout; Publicity Director, George James; Membership Committee Chairman, Herman L. Coplen; By-Laws Committee Chairman, Joseph J. Peterson; Program Committee Chairman, Clair Beighley; and Assistant Program Committee Chairman, Edward Neu. All are connected with the Liquid Rocket Plant of the Aerojet-General Corp. and have been active in rocket development for many years. By-Laws of the proposed organization have been prepared for review by the ARS National Board.

New York Hears Four Experts on Thermal Barrier

By Michael Maccarone

THE problems of the thermal barrier were the subject of a panel discussion at the March 23 meeting of the New York Section.

C. J. Marsel, Section president, introduced the four speakers, all experts in their field.

George Gerard, Assistant Director, Research Division, College of Engineering, New York University, acted as panel moderator and, as the first speaker, set the stage by defining some of the problems encountered by missiles and aircraft in high speed flight. He used a film to illustrate the action of thermal stresses. Then assuming adiabatic aerodynamic heating as the worst condition, Dr. Gerard showed that some cooling is effectively accomplished by radiation, dissociation of air molecules and turbulent rather than laminar air flow.

E. F. Skinner, Head, High Temperature Materials Section, Development and Research Division, International Nickel Co., spoke on high temperature materials, pointing out that molybdenum could be the next most promising material, although it would extend penetration of the thermal barrier only a short distance. Dr. Skinner also discussed the use of protective coatings, such as the ceramics and cermets. He stated that these materials presently have shortcomings in thermal expansion and strength characteristics.

Harold Moak, Director of Engineering, ARDE Associates, discussed the effect of high temperatures on airframes, and Mannie Schneider, Power Plant Staff, Republic Aviation Corp., spoke on cooling high speed aircraft and missiles. He covered advancements in temperature-controlled compartments for pilot comfort and for vital electronic equipment using refrigeration units. Future designs of high speed aircraft will definitely be concerned with such problems as keeping volatile fuels at reasonable temperature limits to prevent high overboard fuel losses even in systems which are slightly pressurized.

Section Doings

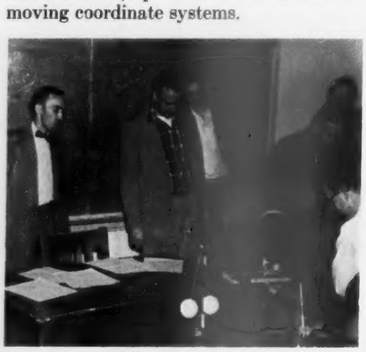
Arizona. Basic problems discussed at the April meeting in Tucson were: Increasing membership, improvement of meetings, financial status, and other related subjects or problems. After the business meeting, officers were elected, a film shown ("The Sky is No Limit") and refreshments served. The film, by Aerojet-General, related to the "Aerobee" sounding rocket.

Cleveland-Akron. At the March meeting, I. I. Pinkel, Chief of the Flight Problems Research Division at NACA, described research on crash fires and human survival in crashes. The impetus for this work comes from the airlines and the Armed Forces who are anxious to improve an already excellent safety record. The talk was illustrated with slides and movies of crash experiments. At the April meeting, Lt. Col. John P. Stapp talked about his research experiences in the field of human adaptation to extreme flight speeds and ejection from supersonic aircraft. His talk was accompanied by motion pictures of experiments on supersonic escape from aircraft. Because of the location of the meeting at the NACA Auditorium, Lewis Flight Propulsion Lab., Cleveland, admission was restricted to U. S. citizens.

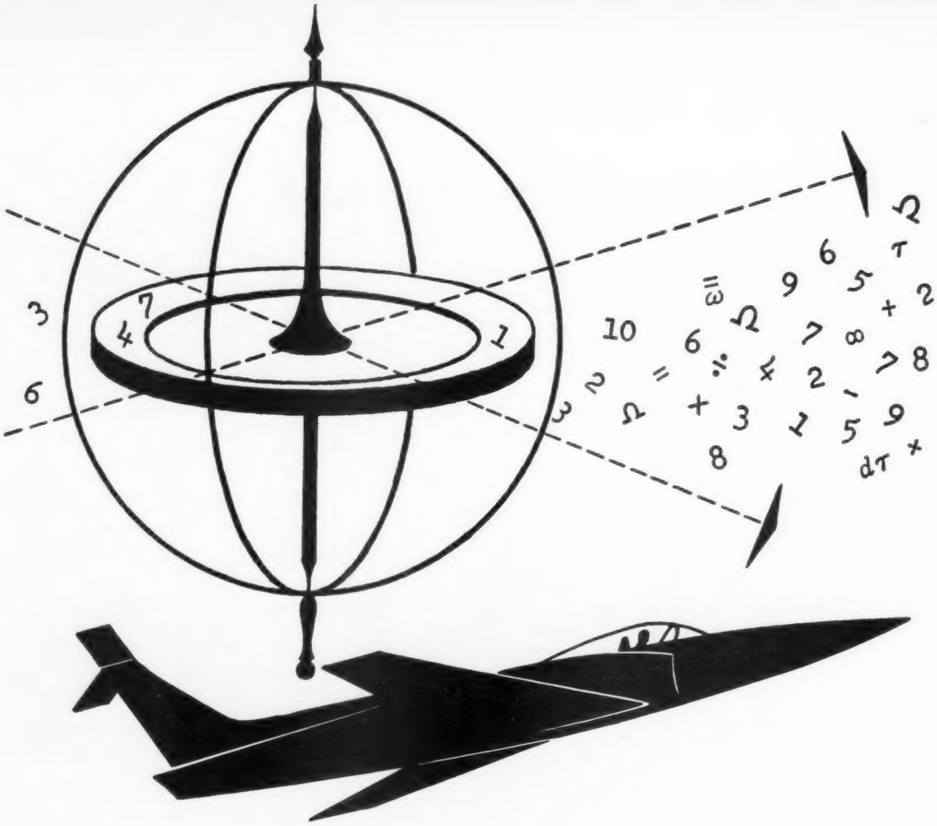
National Capital. Two dinner meetings were held in April. At the first, the speaker was Stanley Smith, chief of Airplane Projects, Bell Aircraft, who described the Bell X-2 and rocket power for future aircraft. At the second meeting, Krafft Ehricke, of Convair's guided missile division, described the use of satelloid vehicles for preparation of manned space flight. New officers announced are: President, Jack Gilchrist (Aerojet); Vice-President, Eric Bergaust (*Aero Digest*); Mason R. Comer, Jr. (NRL); and Treasurer, Richard Snodgrass (NRL).

Norther California. Officers and directors elected at the annual meeting in San Francisco are: *President*, A. J. Eggers, Jr.; *Vice-President*, A. K. Oppenheim; *Secretary*, M. Evans; and *Treasurer*, V. T. Stevens. Directors to serve to 1959: L. A. Walker and K. G. Heller.

New Mexico-West Texas. "Coriolis and the ICBM" was the subject of Harold Daw's talk at the February meeting. Dr. Daw, of the Physical Science Lab., New Mexico College of Agriculture and Mechanical Arts, spoke of the mechanics of moving coordinate systems.



A group watching the effects of coriolis; Dr. Daw is at left



New England. At the February meeting held at the M.I.T. Faculty Club penthouse in Cambridge, attendance numbered 140, largest meeting the Section has had since its founding last July. Speakers were Ernst Stuhlinger, Head, Technical Feasibility Studies Office, Ordnance Missile Lab., Redstone Arsenal; Bruce H. Billings, General Manager, Baird Associates, Inc.; A. John Gale, Head, Development Div., High Voltage Engineering Corp., and M. L. Vidale, Operations Research Group, Arthur D. Little, Inc. At the March meeting, Jean I. F. King, Chief, Radiative Transfer Unit, Geophysics Research Directorate, Air Force Cambridge Research Center, discussed the atmosphere of Venus and Mars. Dr. King described the observation and measurement of radiative heat transfer and evidence of vertical temperature structure in Martian and Venutian atmospheres. Election of officers was scheduled for the April meeting featuring films on the Bell P-59 and X-1A.

Panel participants Billings, Gale, and Stuhlinger

Dr. R. W. Porter, ARS President, at Stuttgart conference with (*center*) Eugen Saenger of the host Forschungsinstitut für Physik der Stahlantriebe, and (*right*) Leonid Sedov of the Russian Academy of Sciences

Rocket Renaissance in Germany

by R. W. Porter

Dr. Porter, 1955 President of ARS, is a consultant with General Electric Company, New York, and is also chairman of the Earth Satellite technical panel on the International Geophysical Year program. He reports for ARS on a recent visit to an international conference of propulsion specialists in Stuttgart.

The revival of scientific effort in Germany is nowhere better exemplified than in the establishment in Stuttgart of the Forschungsinstitut für Physik der Strahlantriebe by Eugen Saenger and Irene Saenger-Bredt. As a symbol of its maturity this Institute held, February 6–8, 1956, in Freudenstadt, Schwarzwald, an international meeting which was attended by representatives of nine countries. The importance of this meeting is indicated by a few of the names in the guest list.

The German government was represented by the Bundesminister für Verkehr, H. C. Seebohm. Other names which may be familiar to readers of Jet Propulsion are: Ernst Heinkel and Generaldirektor Alfred Klein of the Ernst Heinkel Fahrzeugbau GmbH; Silvius Dornier of Dornierwerke GmbH; H. Heinrich, Direktor Robert Bosch, GmbH; Ing. A. Heyser, Aerodynamisches Institut Technische Hochschule Aachen; K. J. de Juhasz, Heidelberg University; O. Lutz, DFL Institut für Strahltriebwerke; Georg Madelung, Technische Hochschule, Stuttgart; F. Nallinger, Chairman of the Board Daimler-Benz AG; Direktor Helmuth Sachse, B.M.W.

A sizable delegation from France included Jean Corbeau, Ingenieur Militaire Principal LRBA, and J. Dupin, Directeur Technique SNCAN; H. Oestrich, Directeur SNECMA, and J. Venturini, President AERA. Other nations represented were: Sweden by Stig Bergstrom and Ake Hjerstrand of the Research Institute of National Defense; Switzerland by A. Gerber, Direktor of Oerlikon; Italy by Giuseppe Gabrielli of Fiat; Holland by A. Hajidakis, Nationaal Luchtvaartlaboratorium, and Meijer-Drees of the Nederlandse Helikopter Industrie; England by D. C. Mandeville of London, and Allan Price, CMG, General Counsel; Stuttgart, Leichtenstein, by H. Thomann, Presz und Stanzwerk AG. Russia was represented by Leonid Sedov, Konstantin Nikitin, and Leonid Popok. The United States was represented by R. W. Porter of the General Electric Company and the National Academy of Sciences; C. J. Pierce, Glenn L. Martin Company, and S. I. Sikorsky, United Aircraft Corporation. Even royalty was present in the person of Prinz Welf von Hannover, younger brother of the queen of Greece.

Social functions included a reception and dinner given by the Bundesminister and cocktail parties by Dr. Porter and Dr. Sedov. As is so often the case, these social activities presented many opportunities for the informal exchange of views which is so valuable in developing understanding between persons of different nationality.

Scientific papers were presented on the subject of ramjet theory and application, liquid rockets, a hot-water rocket, the Oerlikon antiaircraft rocket, and the French research rocket Veronique. Especially interesting were a series of highly technical papers on the subject of the high-temperature plasma produced by electric arcs, on the use of atomic energy in ramjets, and on the flight mechanics of the photon rocket. Professor Sedov presented a theoretical paper covering the aerodynamic theory of the external drag on a hollow cylindrical body. Dr. Porter described in some detail the Earth Satellite Program of the U.S.A.

Active discussion of all of the papers indicated a high degree of international interest in the physical sciences relating to jet propulsion and in their practical application. Not least among the results of this meeting will be the fostering of cooperation among the nations with respect to the exchange of new scientific data and thinking in this fascinating field.

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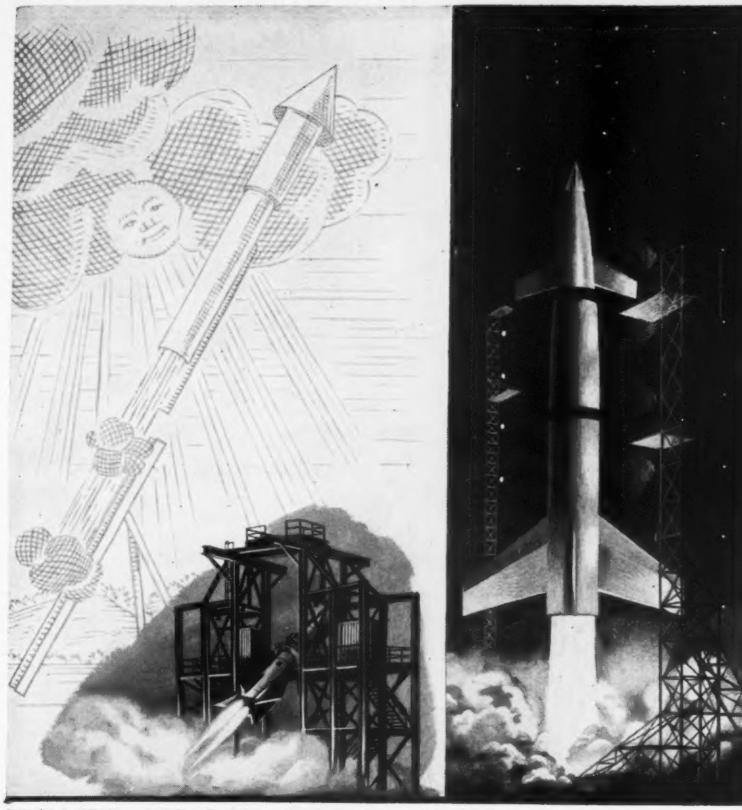

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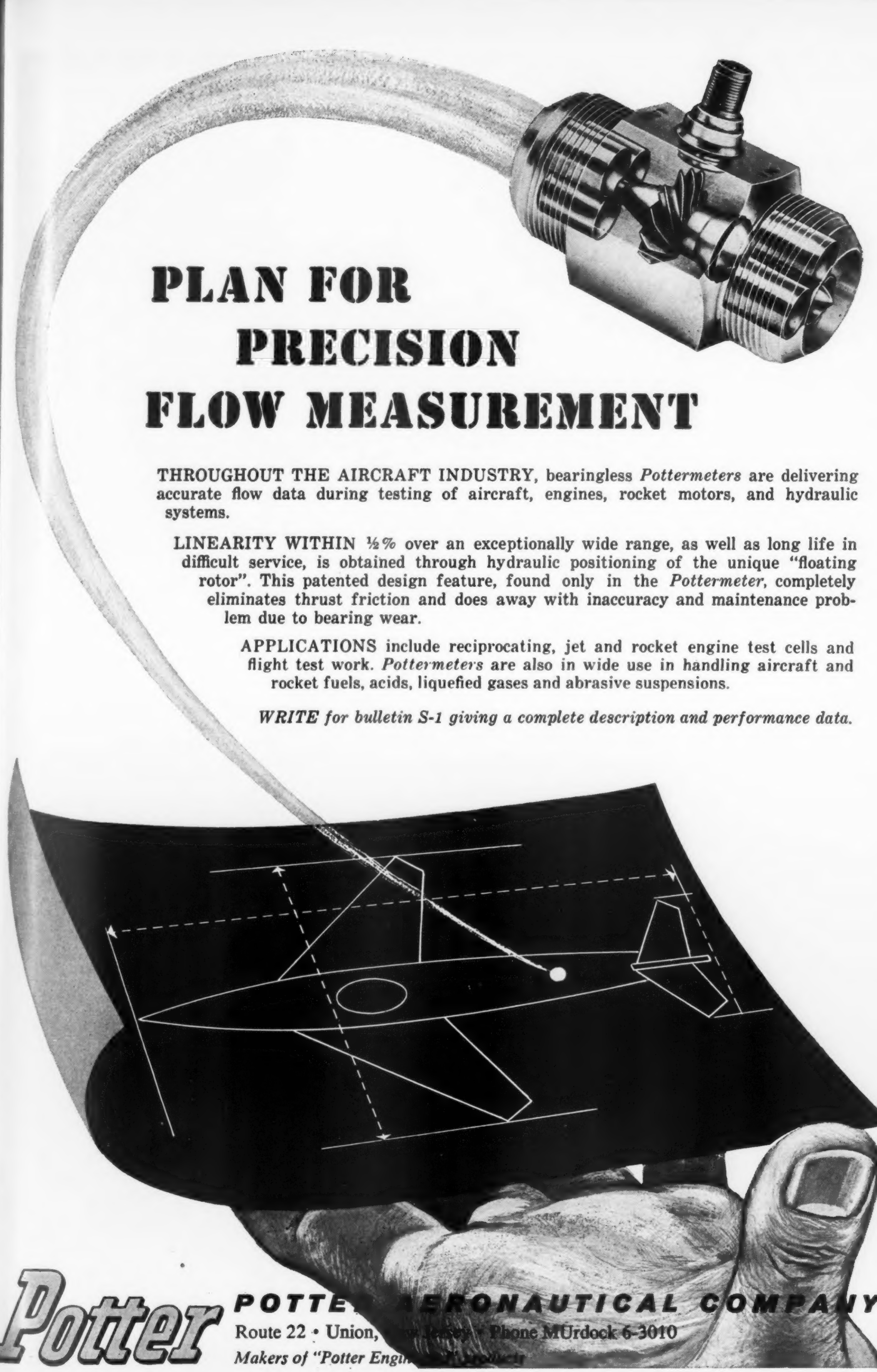
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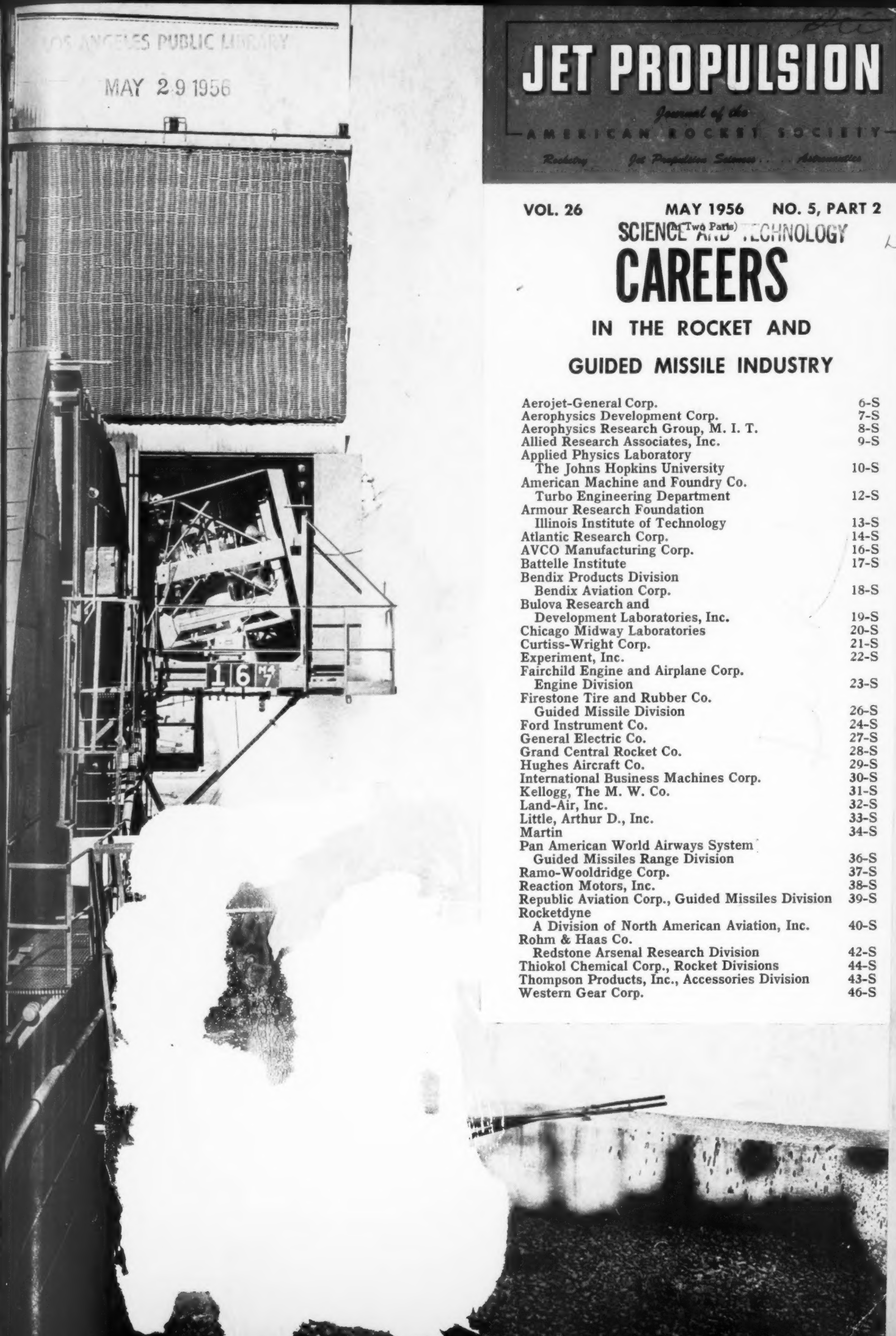

JET PROPULSION

Journal of the AMERICAN ROCKET SOCIETY

Rocketry . . . Jet Propulsion Sciences . . . Astronautics

VOL. 26 MAY 1956 NO. 5, PART 2
(In Two Parts)

SCIENCE AND TECHNOLOGY

CAREERS

IN THE ROCKET AND GUIDED MISSILE INDUSTRY

CAREERS

IN THE ROCKET AND GUIDED MISSILE INDUSTRY

JET PROPULSION

MAY 1956, PART 2

ON OUR COVERS

Front Cover:
Static firing of liquid propellant rocket is depicted. Today's rockets—both liquid and solid—are capable of producing hundreds of thousands of pounds of thrust. Photo is courtesy of General Electric Co.

Second and Third Covers:
Photo taken at 86.1 mile altitude from Viking 11 rocket. Rocket had ascended to 158.4 miles, a record for single stage vehicles which still stands, although attempts to beat it are being made by the Aerobee-Hi as this publication goes to press. Horizon is 830 miles away and distance across horizon is 610 miles. Nose cone, separated from rocket 116 seconds previously, can be seen in middle of third cover. It is about 640 feet away. Photo is courtesy of Naval Research Laboratory.

Fourth Cover

Variety of activities, illustrating diversity of missile field, is shown. Photos are courtesy of (left to right and top to bottom): (1) and (2) U.S. Air Force, (3) Bell Telephone Laboratories, (4) North American Aviation, (5) Martin, (6) Boeing Airplane Co., (7) U.S. Air Force, (8) U.S. Navy, (9) U.S. Air Force, (10) Boeing Airplane Co.

Published by the American Rocket Society, 500 Fifth Ave., New York 36, N. Y.

EDITORIAL

Mild Crisis, Major Counsel Gave Birth to This Supplement

ONE of JET PROPULSION's editors, who also happens to be a professor occupied with research work in jet propulsion, found himself in a small fix a few months ago. He was getting ready to run a jet-mixing test and was looking for his research assistant—an engineering student. The student showed up at the last minute, a sheepish look on his face. Out for a coffee break? No.

"I was being interviewed for a job in X Corporation's missile program. I know it's the third company this week, but I don't want to miss what might be the best opportunity."

This event took place at about the same time that a past president of ARS sent a memo to the Secretariat anent an interesting article he'd just read on the rocket work under way at Z Company.

"Why don't we invite all the missile companies to write articles on what they're doing—and put them in a special publication? Give the students some perspective. Let them know how they fit into the missile picture, how their studies relate to what's going on in research and development, who's doing what work."

"Sure," he went on, "they can get the answers from company representatives on the campus, but how many representatives can a student see and still get his thesis done?"

And so the project got under way, taking form in this Special Supplement.

Although it is being distributed to all ARS members and subscribers to JET PROPULSION, it is slanted—very definitely—to a defined audience: an additional 9496 specific engineering and science students who will receive copies because of the personal interest that 164 professors expressed in their futures.

ARS polled 228 professors—chosen from the Society roster and from an extremely useful directory of university research*—who are *themselves* active in missile research. They were asked (1) if they would distribute copies of the Supplement to the students they felt were interested in, and qualified for the missile field; and (2) how many such students they knew. The response: 164 professors, 9496 students. ARS thanks these professors sincerely for their cooperation and commends them for the interest they took in their pupils.

Thanks are due, also, to the 35 organizations which submitted articles. There has been no editing done on the copy. ARS merely defined the idea for the Supplement to the organizations, and relayed some questions which the professors felt the students wanted answered. The organizations are paying for the space they have used at regular advertising rates for JET PROPULSION. The editors have acted only to maintain uniformity in typographical styling and presentation of the material.

---

* "Review of Current Research and Member Institutions," 1955 edition, published by the Engineering College Research Council, American Society for Engineering Education. Copies available at $2.00 from Renato Contini, Secretary, ECRC, New York University, University Heights, New York 53, N. Y.

An ARS Message to the "9496"

The 9496 students who receive this Supplement will, ARS hopes, eventually become 9496 Student Members of the Society. In fact, an application form has been attached on the last page. You're invited to send it in.

The Society sincerely commends you for your interest in its field and hopes that you find a career with one of the organizations described in the following pages.

A word of caution is in order, though. Enough talk has been heard about the "shortage" of engineers and scientists to impel us to say this: Few, if any, of the organizations represented in this publication suffer from a shortage of applicants. What they suffer from is a shortage of applicants who are competent to handle very difficult problems.

Rockets, missiles, satellites, space travel, nuclear propulsion are intrinsically glamorous fields, but they are practical as well. They require competent people whose vision goes beyond the pages of the textbooks they've studied. Alas, there are no textbooks that can help.

It is our hope that this compilation of articles will assist in linking, in your mind, the fundamental studies you are taking in calculus, thermodynamics, physics, etc., to the real assignments you'll eventually get: determining heat transfer in a rocket combustion chamber; designing a turbopump for propellants; developing the ballistic path for a long range missile.

There is a demand for a broad range of talents—engineers, mathematicians, physicists, chemists; as well as crossbreeds like physical chemists, chemical physicists, aerothermodynamicists.

The work you are liable to undertake is equally diverse. Below, for example, is a listing of titles from recent issues of JET PROPULSION. It demonstrates how theoretical and how practical, how esoteric and how general, how visionary and how contemporary, are the subjects occupying the time of people in the field:

Theoretical

"The Effect of Ambient Pressure Oscillations on the Disintegration and Dispersion of a Liquid Jet"

Esoteric

"Flight Measurements of Aerodynamic Heating and Boundary Layer Transition on the Viking 10 Nose Cone"

Visionary

"Times for Interplanetary Trips"

Practical

"Fabrication of Titanium Components"

General

"Some New Metallurgical Processes of Interest in the Field of High Speed Flight"

Contemporary

"Scientific Uses of an Artificial Earth Satellite"

Of course, it is unlikely that you will be tackling sophisticated assignments right off the bat. However, as one eminent scientist recently told an ARS meeting: "Our organization is forced to place heavy responsibility on young people these days. The situation has its disadvantages, but it has also caused a speedup in the development of some excellent young scientists and engineers."

ARS and, I'm sure, the organizations contributing to this Supplement, hope that your development will be a rapid one, too.

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1949—Leon Cooper, City College of New York
1950—E. Knuth and C. Beighley, Purdue University
1951—L. Rosenthal and David Elliott, California Institute of Technology
1952—Richard W. Foster, Purdue University
1953—Alfred Goldenberg, University of California
1954—No award presented
1955—Richard W. Foster, Purdue University

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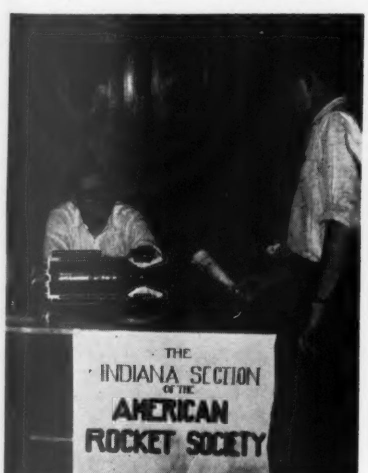
ARS Student Award is presented for the second time to Richard W. Foster at 1955 Annual Meeting in Chicago. Presentation is made by Commander Robert C. Truax, himself an ARS member since his midshipman days at Annapolis, and currently vice president of the Society. In foreground is Joseph H. Kaplan, banquet speaker and chairman of the U. S. National Committee, International Geophysical Year. Dr. Kaplan, also an ARS member, is a leader of the IGY earth satellite program

Evolution of a Missile Engineer

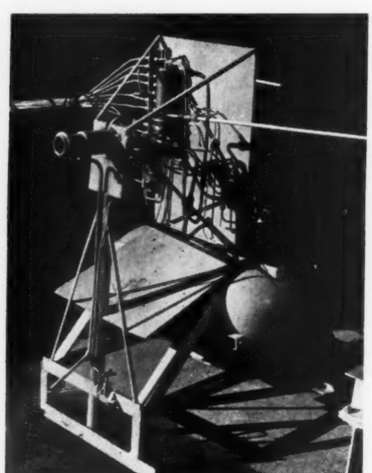
"Student members shall be persons not less than 17 years of age whose principal occupation is study at a recognized educational institution or who are serving as enlisted personnel in the Armed Forces of the United States, and who are interested in the development or application of rocket or jet propulsion." (See application form, p. 47-S and 48-S.)

Richard W. Foster is a 21-year-old mechanical engineer from Purdue University. He is now working on rockets with a leading organization in the field. While at Purdue, he worked as a research assistant under Professor Maurice J. Zucrow at the University Rocket Laboratory where, among other things, he helped to design and build the demonstration rocket engine and test stand shown below. A paper he wrote on this subject won him the ARS Student Award for the second time. He had won it in 1952 for a paper on nuclear propulsion.

During his summer vacations from Purdue he worked on rockets with two different rocket engine manufacturers, thereby adding immeasurably to his appreciation of the value of his college courses.



Foster and Indiana Section President Philip M. Diamond are shown at ARS display at university carnival. Diamond is a graduate student at Purdue



Rocket engine built by Purdue students is seen in action. Firing procedure calls for checkoff of 39 operations. Cost of a 90-second run: $10

Among the other activities that Foster and his fellow ARS Student Members participated in at Purdue were: the publication of a newsletter containing original technical articles on rockets authored by the students themselves; the presentation of a series of public seminars on rocket propulsion, astronomy, celestial mechanics, escape from the earth, step rockets, interplanetary flight and instellar flight; and the preparation of film on experimental firings of rocket motors.

ARS Student Chapters

There are more than 600 Student Members of the American Rocket Society, representing approximately 100 accredited educational institutions.

The first Student Chapter, as such, was chartered less than six months ago at the University of Michigan in Ann Arbor. However, there are several ARS Sections, such as the Indiana Section (*see left*) which have consisted preponderantly of Student Members for some time.

Charters have recently been presented to four other Chapters and another dozen Chapters are in the process of formation.

Student Chapters govern themselves, have their own By-Laws, and receive a modest subsidization from the national organization, as well as assistance in the form of speakers' lists, film lists, stationery, etc. Faculty sponsorship is required, and a group of at least 20 Student Members is required to form a Chapter.

Those interested in forming a Chapter should first seek faculty sponsorship and then communicate with American Rocket Society, 500 Fifth Ave., New York 36, N. Y.

The existing Student Chapters are at:

Academy of Aeronautics, Flushing, N. Y.
University of Michigan, Ann Arbor, Mich.
New York University, New York, N. Y.
Polytechnic Institute of Brooklyn, Brooklyn, N. Y.
St. Louis University, E. St. Louis, Ill.

Student Award

J. B. Cowen, Chairman of the 1956 Awards Committee, has established a deadline date of August 15, 1956, for entries in this year's ARS Student Award competition.

Papers may deal with any subject within the scope of ARS interest—rockets, ramjets, space flight, combustion, and will be judged on the basis of accuracy of expression, understanding of the subject and originality of thought.

A medal will be awarded to the winner at the Annual Meeting Banquet in New York in November.

Send entries to:

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Aerojet-General Corporation

Azusa and Sacramento, Calif.

THE Aerojet-General Corporation is America's leading industrial organization devoted to research, development, and manufacture of rocket engines and related devices. Our principal products are the following: solid- and liquid-propellant rockets for assisted take-off and in-flight thrust augmentation of piloted aircraft; solid and liquid propellant boosters and prime power plants for missiles; thrust reversers; auxiliary power units and gas generators; upper-atmosphere research rockets; underwater propulsion devices; electronics and guidance; ordnance rockets; explosive ordnance, warheads, and armament; flame throwers; propellants and propellant chemicals; primary batteries. In addition, Aerojet designs and constructs complete rocket and missile launching and testing facilities throughout North America. Aerojet employs over 7000, and sales for 1956 exceed $90 million.

The company's decentralized organization, indicated by the nine operating divisions listed below, has been a major cause for its leadership in the constantly expanding rocket powerplant and missile field.

- Liquid Engine Division
- Solid Engine and Chemical Division
- Manufacturing Division
- Test and Field Service Division
- Liquid Rocket Plant, Sacramento
- Solid Rocket Plant, Sacramento
- Electronics and Guidance Division
- Architect Engineering Division
- Underwater Engine Division

Backed by the resources of The General Tire & Rubber Co., Aerojet has established a solid foundation for unlimited growth in an unlimited industry. Led by president Dan A. Kimball, former Secretary of the Navy, Aerojet has acquired a team of management and technical personnel of the highest caliber. Our Technical Advisory Board, for example, includes aerodynamicist Dr. Theodore von Kármán; astrophysicist Dr. Fritz Zwicky; aeronautics expert Dr. Clark B. Millikan; pioneer rocket authority Dr. Bruce Sage; General of the Army Omar N. Bradley; Rear Admiral Calvin M. Bolster, USN (Ret.); and Major General Arthur W. Vanaman, USAF (Ret.).

The Aerojet team has successfully accomplished many "breakthroughs" on the technical and industrial frontiers. A few of these firsts are:

FIRST	American power plant for rocket-powered piloted aircraft
FIRST	American solid-propellant JATO rocket engine used on Service aircraft
FIRST	production line for liquid-propellant rocket power plants
FIRST	quantity production of high-altitude rocket test vehicles
FIRST	American continuously operating liquid turborocket
FIRST	Manufacture of booster rockets exceeding 100,000 lb thrust
FIRST	Underwater jet propulsion engine
FIRST	CAA-approved rocket engine for commercial use.

Aerojet's three plants are located in the dynamic and exciting state of California. A career with Aerojet will give you and your family a full and interesting life in either the Sacramento River Valley (the location of our two Sacramento plants) or the San Gabriel Valley (site of our Azusa facility). Either valley offers western living at its best. Top ranking schools, modern shopping centers, attractive western-style homes, outstanding recreational facilities, and a splendid scenic panorama create a thoroughly enjoyable environment for Aerojet employees and their families.

Aerojet-General Corporation offers a full program of benefits directed toward employee welfare and security:

Free Group Insurance—Excellent surgical, hospital, medical, major medical, and life coverage for employees

Vacation—Two weeks after one year; three weeks after fifteen years' service

Holidays—Six paid holidays

Sick Leave—Ten days a year cumulative up to 40 days

Retirement Plan—The company's large contribution plus a contributory feature provide a comfortable income to participants upon retirement—eligibility for participation after one year as an employee

Educational Refund Plan—Two-thirds of college level study costs reimbursed for qualified personnel

Orange Belt Graduate Program—A master's degree in engineering from the University of California may be obtained through evening classes attended in the San Gabriel Valley.

Additional benefits are provided via the Aerojet blood bank (available free not only to employees but to their families), and the many social and "helping-hand" activities of our Welfare and Recreation Club plus a well-stocked employees' store offering quality merchandise at substantial savings.

At Aerojet, you will work with some of America's foremost authorities in the rocket and missile field, whether your primary interest is pure research, development, or manufacture.

In research, Aerojet offers outstanding opportunities for engineers and scientists in the fields of aerodynamics, heat transfer, thermodynamics, instrumentation, high-temperature materials, structures, electronics, gas dynamics, and automatic controls. In production, our interests range from underwater propulsion devices to upper-atmosphere rockets.

In the large-scale manufacture of critical new missiles for the Armed Services and rocket motors for civilian and government use, Aerojet-General's organization and facilities are second to none. With the constant expansion of all of the Aerojet plants there are excellent prospects for engineers, chemists, physicists, and mathematicians with an eye toward an active, challenging future and an interest in intriguing, varied activity.

Aerophysics Development Corporation

A Studebaker-Packard Subsidiary

Santa Monica, Calif.

AEROPHYSICS Development Corporation (ADC) is a highly specialized and progressive research and development organization presently engaged in the development of a missile for the United States Army, a research missile for the United States Air Force, and various other classified research projects for the military services and the Atomic Energy Commission. The company was organized in 1951 by Dr. William Bollay, the current president and technical director, a well-known scientist with many years' experience in the fields of aeronautics and rocketry. The principal objective of the organization is to carry out research and development on interesting and important new projects which promise major advances in the various fields of aerophysics. At present ADC is concerned primarily with military projects; however, the techniques now being perfected will also be applied to industrial and commercial applications in the future.

Recently Aerophysics became a wholly owned subsidiary of the Studebaker-Packard Corporation. Its role in research and development has remained the same, and with the backing of the parent organization a complete system is now available for carrying new ideas from initial research, through development to final production.

In its rapid expansion over the past five years the company has increased its staff from zero to over five hundred scientists, engineers, technicians, and supporting staff. The organization has approximately doubled in size each year and thus ADC represents the opportunities for growth for bright young engineers which are only available in an expanding organization. Many of the present staff members have been among the leaders in developing the revolutionary advances made in the field of aeronautics during the past decade—in supersonic aerodynamics, in jet and rocket propulsion, and in guided missiles.

Organizationally the company is set up in project and technical sections including aerodynamics, flight test, design, electromechanics, structures, and shop. Special projects include systems and systems analysis, propulsion analysis and research, and other activities which fall in the highly classified areas and cannot be discussed.

Careers are available in all phases of engineering and science. The major projects are long range in nature and offer creative and challenging opportunities for the individual. ADC is still a small company and due to its compact organization can offer an individual the opportunity to see the way his particular effort fits into the over-all company program. Every Aerophysics employee is given the opportunity to increase and improve his individual capacities and contributions to the group effort. Each person at Aerophysics is evaluated periodically on the basis of the contribution he makes to the company's progress through his effort, and a man is judged primarily on his technical contribution rather than upon the number of people he supervises.

Training programs are now being established for young engineers and technicians. In addition, the company offers an educational refund plan which covers part of the cost incurred by an employee taking supplementary education. A number of the scientific and administrative employees inside the company are certified to teach university courses for which college credits may be obtained.

Late this year the permanent home facility for Aerophysics will be a new plant now under construction in Santa Barbara, Calif. This delightful year-round resort is a cultural and educational center located approximately ninety miles north of the city of Los Angeles, on the Pacific seacoast. There is a wide range of activities available in this area. The University of California has a branch located there and there are museums, botanic gardens, theaters, fine restaurants, boat harbor, and many other social and cultural interests. All types of housing are available in every price range. Aerophysics management picked the Santa Barbara area because of its exceptional atmosphere for both work and play. The most modern principles of building design are being incorporated in the construction of Aerophysics Development Corporation headquarters plant to provide the ideal atmosphere for research. Excellent shop and laboratory sections will enable the skilled technician to produce the best results for which he is qualified. Ample parking areas are planned and commuting to and from work is a leisurely, traffic-free pleasure amid magnificent mountain and seacoast scenery.

Within the company itself a great many social and athletic events are programmed. Parties, picnics, and dances are sponsored by the Employees Association. Baseball, bowling, skiing, public speaking, and other clubs engage in interdepartmental competition. The company also provides vacation, sick leave, and insurance benefits.

In the future, Aerophysics will continue its intense program of research and development in the field of missiles. Application of today's technical developments will produce better missiles and missiles systems tomorrow. A great many of the ideas and techniques now being developed by Aerophysics can and will be used in commercial and military aeronautics of the future to contribute to our country's scientific leadership.

Aerophysics Research Group

Aeronautical Engineering Department
Massachusetts Institute of Technology
Cambridge 39, Mass.

Scope

THE Aerophysics Research Group of the M.I.T. Aeronautical Engineering Department is engaged in sponsored research which may be especially attractive to those engineers who desire to obtain an advanced degree. Research programs are being conducted in the fields of missiles dynamics and control, aircraft dynamics and control, cruise control techniques and instrumentation, missile and satellite trajectories, transonic and supersonic wind-tunnel testing, and viscous compressible fluid dynamics.

Organization

A research group at M.I.T. is under the over-all direction of senior faculty members. A group usually handles several projects, each of which is supervised by a member of the faculty who works closely with the project leader. As a general rule, other academic staff members are affiliated with the projects in either a consulting capacity or as active workers. In this way, a close relationship between the teaching and research staff is maintained.

Faculty Members

Professor Walter McKay provides the over-all direction of the Aerophysics Research Group, while Professors Paul E. Sandorff, Yao T. Li, and Joseph Bicknell supervise the three general fields of missiles and satellites, cruise control techniques and instrumentation, and dynamic stability and wind-tunnel testing, respectively. Professors H. G. Stever, E. E. Larrabee, and L. Trilling are also affiliated with the Group in their respective fields.

Work Being Performed

Missiles and Satellites

Professor Paul E. Sandorff supervises the effort of the Group in this field, which is mainly concerned with the trajectories and dynamics of nonballistic and ballistic long-range missiles. The development of analytical techniques for determining trajectories, the analysis of missile structural dynamics, and the study of aerothermodynamic effects are a few of the specific topics on which research is being done.

Cruise Control Techniques and Instrumentation

Professor Y. T. Li supervises the Group's effort in this field. The work falls into the two major areas of cruise performance analysis and optimalizing control.

The fundamental theory of cruise performance together with the cruise characteristics of many current and future aircraft designs are being studied in detail. Additional work on the characteristics of gas turbine engines is contemplated. These investigations provide the background essential to the development of improved cruise control techniques and instrumentation.

Optimalizing control is that branch of instrumentation dealing with controllers that automatically maximize the performance of a system. At present, an experimental optimalizing cruise controller for turbojet aircraft is under construction. The extension of this work to turboprop power plants is under consideration.

Dynamic Stability and Wind-Tunnel Testing

Experimental and analytical dynamic stability investigations are conducted under the supervision of Professor Joseph Bicknell. These investigations employ the analog and digital computing facilities for their analytical phases and the transonic-supersonic blowdown wind-tunnel facility for their experimental phases. In addition, related problems in compressible viscous fluid dynamics are studied theoretically and experimentally in a special boundary layer research wind tunnel. Specific topics of investigation include inertial cross coupling, stability derivative extraction from flight data, dynamic stability derivative measurement, and shock wave boundary layer interaction.

Facilities Available

The facilities available to a research engineer at M.I.T. are many and varied. On the technical level are several analog and digital computing facilities, a trisonic wind tunnel facility, instrument and electronic laboratories, and metal and woodworking shops. The computing facilities include a double REAC, two suppressed-time-scale analog computers, two IBM 650 computers, and the Whirlwind I digital computer. The trisonic wind tunnel facility is composed of the Wright Brothers Wind Tunnel with an operating range of 0 to 150 mph, the Transonic Blowdown Wind Tunnel with an operating Mach number range of 0.7 to 1.2, and the Supersonic Blowdown Wind Tunnel with a continuously variable Mach number range of 1.2 to 2.1.

On the recreational level are the athletic facilities of the Institute, including its indoor swimming pool, squash and handball courts, tennis courts, ice rink, and sailing fleet. The Research Staff Member is also eligible for membership in the M.I.T. Faculty Club after an employment of one year.

Advantages at M.I.T.

The most important advantage of working at M.I.T. is the opportunity to engage in advanced study and to work toward an advanced degree in one of the topmost engineering schools of the world. All research staff members are permitted to register for one course per semester with no reduction in salary for time taken off from work. Research Assistantships are also available for those who qualify as graduate students and register for sufficient graduate subjects.

In addition, the engineer who becomes a member of the M.I.T. Research Staff works on challenging research problems in collaboration with faculty members who are recognized authorities in their respective fields. The project organization permits an engineer to participate in all stages of the solution of the research problem: conception, theoretical development, analysis, design of hardware, fabrication, and test.

Engineering Openings

The Aerophysics Research Group is in need of college graduates having degrees or experience in aeronautical, electrical, or mechanical engineering. Men with experience and advanced degrees are needed, as well as B.S. degree holders with no experience at all. Those engineers who are interested should contact Mr. Thomas R. Parsons, Executive Officer, Aerophysics Research Group, Room 41-203, Massachusetts Institute of Technology, Cambridge 39, Mass.

Allied Research Associates, Inc.

43 Leon Street, Boston, Mass.

ALLIED RESEARCH ASSOCIATES, INC., a young organization of research and development engineers, was formed for the purpose of providing a pool of highly skilled scientific personnel capable of undertaking some of the many problems in research and engineering development which now confront industry and government on all sides.

Allied's scope is broad, and its specialized know-how focuses on problems ranging from guided missile study and atomic weapons effects to the analysis and control of environmental vibrations.

Solving Problems in Many Fields

Guided Missile Design Studies

Allied's well-rounded background in this field includes experience in vehicle design—both aerodynamic and structural—liquid and solid fuel propulsion systems—and guidance, fuzing, and warhead evaluation. A project for the immediate future: studies of still further advanced methods of propulsion.

Thermoelastic Research

Allied has extensive experience in thermoelasticity and thermoplasticity. It has participated in full-scale testing of models instrumented to record temperature distribution, thermal stresses and deflections, and is currently engaged in coordinated theoretical and laboratory studies of this nature, including research on missiles and aircraft in supersonic flight.

An engineer is conducting a test to determine the stress and deflection response of a plate to thermal radiation

Aerodynamics Research—Aircraft Operations

Much of Allied's research in this field is concerned with aerodynamic analysis as well as operational and performance characteristics of propulsion units and various types of aircraft. Allied's location permits ready access to excellent experimental facilities, including both low- and high-speed wind tunnels.

Structural Dynamics

Evaluation of the structural integrity of aircraft is vital—and some of Allied's more important research has been in this direction. In particular, the response of aircraft to various transient aerodynamic inputs is currently being performed—studies which include nonsteady aerodynamics and various rigid-body and elastic modes.

Vibrations Analysis and Testing

Allied has accumulated an extensive backlog of experience in theoretical and experimental analysis of the vibration behavior of complex systems, including the flight testing of airborne equipment. A vibration isolation unit of unique design, recently developed by Allied, is planned for production in the near future.

Mechanical and Structural Design

Many of the design problems met in the application of nuclear energy to commercial uses can be competently handled at Allied.

Atomic Weapons Effects

Studies associated with this work include analyses of blast, thermal, and nuclear radiation effects, and the determination of safe and lethal regions for aircraft operating in the vicinity of a nuclear burst. Allied personnel have participated in atomic field operations at both the Nevada and Pacific Proving Grounds.

Physics and Physical Chemistry

Many of the above fields produce problems in physics and physical chemistry. Current projects include theoretical and experimental work in high temperature physics, explosives, radiation transfer, and instrumentation.

Facilities...

Engineers are assigned to problems on a project basis at Allied, and work in closely knit teams—so the engineering offices are arranged to permit closest liaison among staff members. An engineering library makes available the latest classified and unclassified technical reports, and in addition, the many nearby universities provide access to some of the largest technical libraries in the country.

The instrumentation laboratory, machine shop, and offices, covering approximately 35,000 square feet, are fully equipped to support Allied's wide ranging research operations. Allied maintains staffs of draftsmen, electronics technicians, and engineering computers, as well as a fully manned technical publications department. Experimental and automatic computation facilities for analytical and experimental research are readily available.

You and Allied—Opportunities

Allied offers opportunities for engineers and physicists in these expanding fields: propulsion systems; theoretical and applied aerodynamics; nonsteady aerodynamics; aeroelasticity; thermoelasticity; vibrations analysis; structural dynamics; structures and elasticity; weapons effects; high temperature physics; spectroscopy; instrumentation; and radiation transfer.

The young engineer who wants a career in one of these fields finds a stimulating atmosphere for growth at Allied. He is assigned to work on a project basis—and as a member of a team, is given considerable independence and responsibility for the success of his phase of the program. He has a clear view of the importance of his contribution to the over-all project from beginning to end.

The "team concept" of Allied's research minded management permits maximum cross-fertilization of ideas and talents which broadens the background and enhances the technical growth of the individual. Policy dictates promotion from within, and the young engineer can look forward to directing a project as soon as his ability permits.

In addition, Allied maintains a flexible policy encouraging its engineers to take advantage of further opportunities for education at nearby universities.

Few areas in the United States are so rich in engineering knowledge and technical sophistication as the New England area in which Allied is located. But cultural and intellectual facilities are just one of the area's attractions—for New England is an ideal place to live. Living conditions are excellent, both in the city of Boston itself and in the outlying suburbs. Distances are short—and the mountains, the lakes, and the ocean are within easy reach for winter or summer recreation.

Applied Physics Laboratory

of The Johns Hopkins University

Silver Spring, Maryland

Background

THE work of the Applied Physics Laboratory was initiated in the summer of 1940 under the National Defense Research Council, a group of the nation's scientists brought together to focus technical resources on the development of new and more powerful weapons for the Armed Services. Among the urgent problems considered by this group was the defense of the fleet against air attack.

After studying this problem it was decided that influence-type fuzes for antiaircraft shells would be feasible and, if successfully developed, would constitute a major advance in the technology of air defense. The Office of Scientific Research and Development asked The Johns Hopkins University to accept a contract to carry out this program, and the University established the Applied Physics Laboratory to perform this research and development and coordinate the work of other contractors.

The striking successes of scientists at the Laboratory and their associates in industry and at other universities constitute one of the principal technical achievements of World War II. Within six months, production of the first fuzes was begun. They were first used in action by the *USS Helena* north of Guadalcanal in January 1943. Fuzes developed by the Laboratory later played an important role in the defense of Britain against V-1 missiles and as antipersonnel and antitank weapons by the Army Ground Forces. As a second step toward increasing the Navy's air defense, the Laboratory developed radar-controlled gun directors for 5-inch and 40-mm guns.

Program Scope

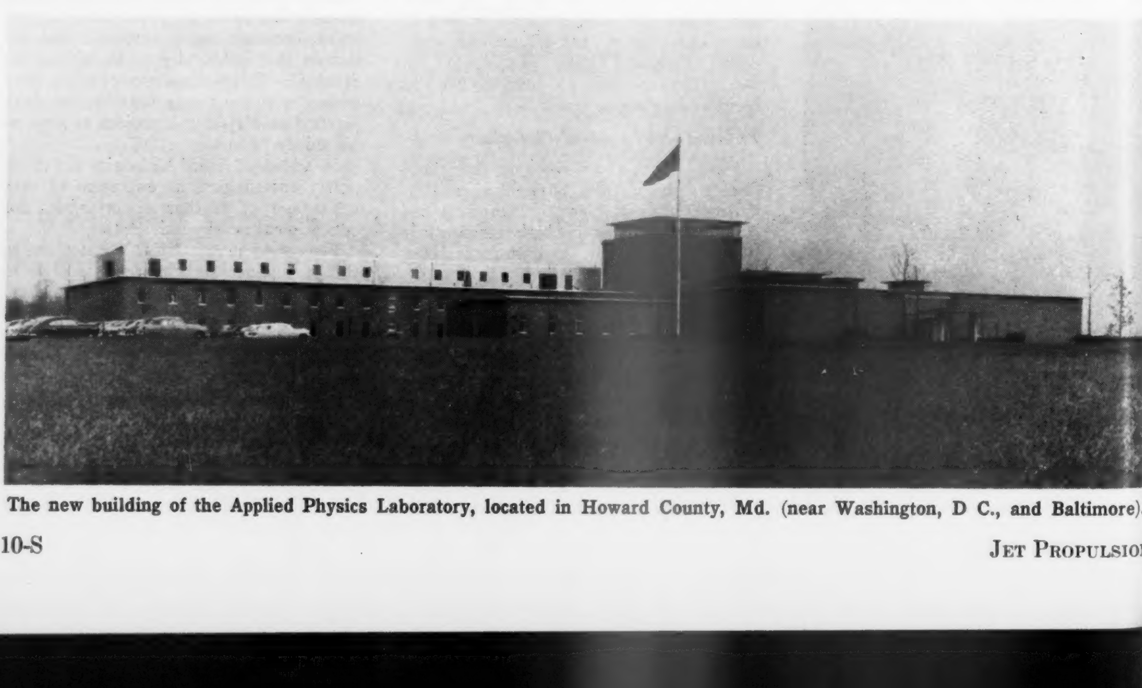
For the past ten years the principal effort of the Applied Physics Laboratory has been devoted to the development of guided missiles, under a broad program having the code name "Bumblebee." Since the early days when it had 50 staff members, the Laboratory has steadily grown into an organization having a staff of 1200—500 of whom are professional engineers and scientists.

In 1945 techniques for launching, propelling, and guiding a supersonic missile were wholly unexplored. As a first step the Laboratory established research and development teams in each of these fields, and university and industrial contractors having special skills were brought in to make a concerted attack on the many problems that had to be solved. Development facilities to furnish realistic data on the performance of missile component systems were built. These included the first large-scale supersonic wind tunnel and ramjet testing facility, electronic flight simulators, flight test ranges, and the development of telemetering to transmit accurately the action of missile components in flight.

With this systematic and comprehensive effort, pioneering advances came rapidly. The first successful ramjet was flown in June 1945. The first large booster rocket was developed in 1946. The first demonstration of control at supersonic speeds was made in 1947. Finally, fully guided supersonic flight was achieved in 1948. These accomplishments in the newly born field of guided missiles provided much of the fundamental understanding that has been the basis for a large part of the country's guided missile effort.

Having devised solutions to the essential problems of launching, propulsion, guidance, control, and warheads, the Laboratory took steps to design and build complete missile prototypes. This was accomplished with the aid of industrial "Associate Contractors" who also participated in the development programs under the technical direction of the Laboratory. The results were so manifestly successful that the Navy promptly placed direct procurement contracts for final engineering and production of the entire weapon system based directly on these prototypes and on specification requirements prepared by the Laboratory. Today, two missiles that grew out of the Bumblebee program are in production; one of these, the TERRIER, has gone through Fleet evaluation and has become a Service weapon; the other is the supersonic ramjet-propelled TALOS.

The initial objectives of the Laboratory's guided missile program have been met; and a new phase, resembling in many respects the first development phase, has begun. The rapid growth of technology throughout the world has greatly increased the capability of the enemy to deal a devastating blow from the air. By the same token this growth has created the possibility of major extensions in per-



The new building of the Applied Physics Laboratory, located in Howard County, Md. (near Washington, D C., and Baltimore).

formance of guided missiles for defense or retaliation. As a consequence several new major programs have emerged from the basic Bumblebee program as prime objectives for the next five to ten years. There is no diminution in sight for challenging new technical problems.

In addition to the groups at the Laboratory responsible for applied research, development, and engineering of missiles and missile systems, a sizable fundamental research effort has existed since 1948, when the Research Center was founded.

Staff members of the Research Center conduct basic experimental and theoretical studies in selected areas of interest to the Laboratory; that is, in those areas that would offer the best hope of success in finding needed knowledge or those that would supply a breakthrough on the frontiers of scientific exploration that might lead to the initiation of a new Laboratory activity.

Although there are no mutually exclusive groups in the Research Center, its work generally may be said to apportion itself in the broad fields of chemical, electronic, and microwave physics, and in theoretical and applied mechanics.

At the Applied Physics Laboratory it is believed that a strong fundamental research effort is a necessary companion to present developments, tending to fortify and refine them, and a necessary sentinel to future developments, tending to seek out and signalize the most promising.

Professions

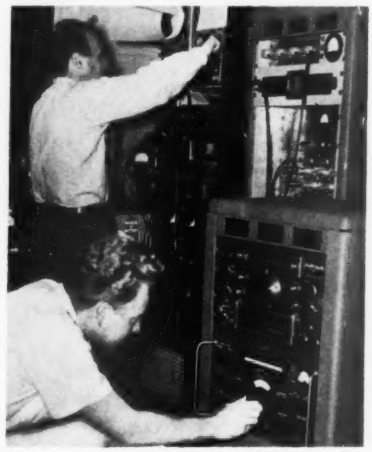
The Applied Physics Laboratory is primarily an organization of and for technical men and scientists—engineers, physicists, mathematicians, chemists, and others.

Two features distinguish the organization: the self-dependence of the professional staff and the fluidity of relationships among the groups engaged in the many areas of technical endeavor.

The Laboratory has broken its total mission down into fields, such as missile control systems, aerodynamics, and propulsion. To undertake the study of problems in these fields, teams of staff members drawn from all requisite professions are brought together. Each team maintains a balance between research at the one end and engineering of the final prototype at the other, with all necessary gradations of analytical and experimental design lying within the extremes. This results in an individual staff member's having a broad knowledge of and interest in the problem under attack, which leads to heightened individual creativeness. Similarly, technical freedom and cooperation among teams are fostered, assuring that the solution to any one team's problem will be a well-integrated and compatible part of the over-all objective.

The major professional activities in which the Laboratory is engaged may be broken down into the following five categories. In most of these there is a present need for additonal staff members at all levels of experience.

1. *Electronics Research and Development*—guidance, control, telemetering, and data-handling systems; computer design; transistor and magnetic-amplifier applications; countermeasures; over-all missile systems design; dynamic studies; electronic packaging; flight test engineering.
2. *Aerodynamics*—stability and control analysis, preliminary design, and wind-tunnel testing.
3. *Mechanical and Aeronautical Design*—airframes and structures, mechanisms, launching and handling systems, ramjet propulsion, warheads.
4. *Analysis*—over-all systems and operations; electrical noise and interference; stress, dynamic, weights and loads; the effectiveness of warheads; flight simulation.
5. *Research*—combustion, solid-state physics, shock-wave phenomena, and other studies in chemical, electronic, microwave physics and in theoretical and applied mechanics.



Scientists engaged in microwave research at the Applied Physics Laboratory

Facilities

The buildings of the Applied Physics Laboratory are located in Silver Spring and Howard County, Md., conveniently situated with respect to residential suburbs of both Washington and Baltimore.

The buildings are modern and air-conditioned and are exceptionally well equipped for research and development activities. A complete environmental test laboratory, large electronic analog and digital computers, a burner facility for testing models of ramjet engines, and a hypersonic wind tunnel for research are but a few examples of the range and wealth of equipment available to the staff. All important publications and books in the guided missile field and related fields are available through the Library at the Laboratory, which, in addition to being excellent in itself, also has access to the Library of Congress, the University Libraries in Baltimore, and the libraries of government agencies.

Living

The central position of Washington in the nation's cultural life is assured by the National Gallery of Art, the Smithsonian Institution, the National Symphony, and the memorials to Washington, Lincoln, Jefferson.

Washington suburbs neighboring the Laboratory in Montgomery County, Md., include Bethesda, Kensington, and Takoma Park. On the edge of Baltimore are Ten Hills and Hunting Ridge, and many staff members live in Catonsville.

The community has one of the highest standards of living in the country. Its advanced public school system has been rated by the Office of Education as one of the Nation's twelve best.

Centrally located on the Eastern seaboard, the region is connected by rail and highway with such major cities as New York, Philadelphia, and Richmond. Scenic areas, such as the Skyline Drive, Harper's Ferry, the Shenandoah Valley, historic Williamsburg, Annapolis, the Chesapeake Bay, and ocean resorts on Maryland's eastern shore are within a few hours' journey.

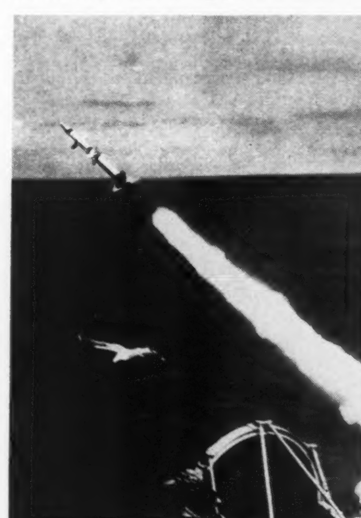
Benefits

The major benefit programs offered by the Laboratory include paid vacation and sick leave, pension and group life insurance, education benefits, a credit union, and recreational facilities and activities.

The vacation enjoyed by staff members varies from two to four weeks per year depending on staff level and length of service.

Educational assistance in the form either of time off or remission of tuition is granted staff members taking college work, at the junior level or higher, in any of the area's fine schools: Johns Hopkins University, University of Maryland, George Washington University, Catholic University, Georgetown University, and American University.

Organized but informal after-work recreation has been a part of the Applied Physics Laboratory since it was established. Today members have expanded their leisure-time activities to include bowling, golf, archery, chess, rifle shooting, private flying, choral singing, group and Laboratory-wide outings, and dances.



The Navy's Terrier missile, developed by APL, launched from the *USS Mississippi*

American Machine & Foundry Company

AMF Building, 261 Madison Ave., New York 16, N. Y.

• • • Engineers • • • Engineers • • •

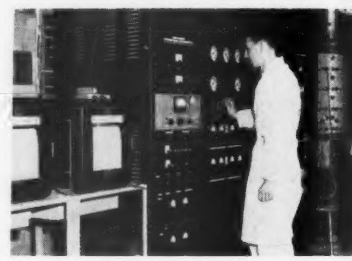
The rapid growth of the Turbo Division has created additional job opportunities for Engineers in design, development, and production engineering of Accessory Power Supplies for Guided Missiles.

Design Engineering

• • • Important • • •

Our constant growth and expansion, our success—are based upon our policy of hiring the very best of engineering talent and giving each man individual recognition and reward for his achievements.

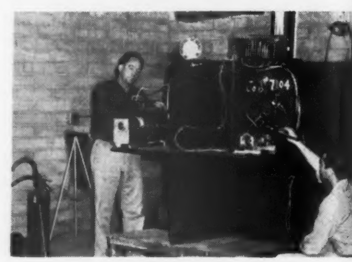
The utmost in imaginative and creative effort is required in exploring the largely uncharted technical areas in the auxiliary power systems field.



Instrumentation

Engineering Positions open at all Levels

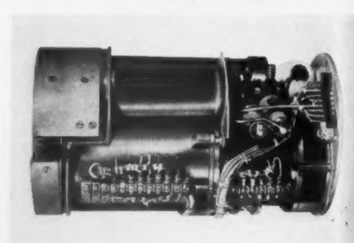
Electronic Circuitry
Magnetic Amplifiers
Servomechanisms
Development Engineers
Design Engineers
Thermodynamics
Rotating Machinery (Electrical)



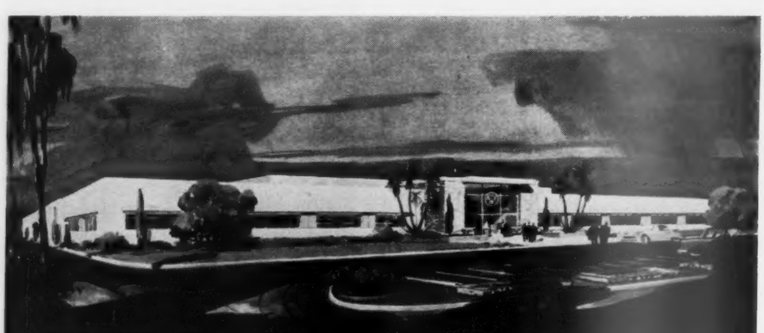
Prototype Testing

• • • Benefits • • •

Relocation expenses, tuition reimbursement plan, and a comprehensive benefits program are offered by AMF, one of the larger diversified growth companies.



Typical Accessory Power Supply



Turbo Division—American Machine & Foundry Company's facility on the West Coast will soon be located in this modern headquarters at Pacoima in the San Fernando Valley

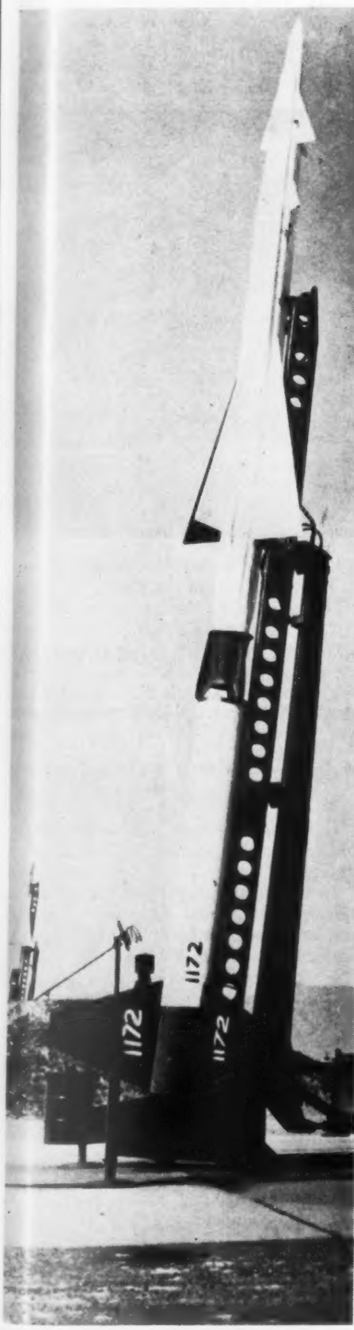
Please address complete résumé outlining details of your technical background to:

Mr. Fred Barge
Turbo Division
American Machine & Foundry Co.
12270 Montague Street
Pacoima, California

Armour Research Foundation

of Illinois Institute of Technology

Chicago, Ill.



NIKE launching section with missiles raised to firing position

ARMOUR RESEARCH FOUNDATION, one of the nation's largest and best known independent industrial research organizations, is currently celebrating its 20th year in the field of research and development.

At the present time the Foundation employs more than 1100 full-time staff members and has an annual research volume of about $11,000, 000.

During the past fiscal year, ARF has conducted 512 research and development projects. Of this number, 342 were for industrial concerns or trade associations and 160 for government agencies.

The Foundation recently announced that it expects to have a research volume of $16 million and a staff of 1600 by 1961.

Armour Research Foundation is located in 15 buildings on Chicago's near south side in a 110-acre area known as Technology Center. Currently it is engaged in a $5 million expansion program which will add three new buildings and additions to two others.

One of the outstanding features of this expansion program is the construction of the nation's first nuclear reactor for industrial research.

To assist the professional growth of its staff members, the Foundation maintains its own educational program. ARF bears all tuition costs for courses taken at the Institute under this program.

Currently the Foundation is engaged in research work in the fields of ceramics and minerals, chemistry and chemical engineering, electrical engineering, engineering economics, propulsion and fluids, mechanical engineering, metals, and physics.

Armour Research Foundation has developed the world's largest shock tube to study the behavior of air at very high temperatures and pressures similar to those produced by an atomic bomb, the sun—or by a rocket or missile.

While the effects of bomb blasts on structures can be studied in the laboratory, primarily to save money, the effects of guided missiles in the air practically must be tested in the laboratory. This is necessary because after a few minutes of flight a real guided missile is a thousand miles away from its firing point and it is virtually impossible to achieve the required experimental control in the missile.

The Foundation also has developed several other shock tubes, including one equipped to take photographs of blast wave phenomena, and another, which is six feet in diameter by 150 feet, to generate intense or "strong" shock waves needed in studies related to intercontinental missiles and rocket propulsion.

Some of the fields in which ARF is equipped to carry on research relating to rockets and missiles are:

Rocket development
Operations research
Aerodynamics
Data processing
Instrumentation
Systems engineering
Vibration and shock
Heat transfer
Countermeasures
Propulsion
Structures
Electronics
Computers
Controls
Gas dynamics
Ballistics
Combustion
Propellants

If you are interested in the unusual opportunities available at ARF write to:

Personnel Manager
Armour Research Foundation of
Illinois Institute of Technology
Technology Center
10 W. 35th St.
Chicago 16, Ill.

The Falcon missile scores a hit on a drone aircraft

Atlantic Research Corporation

Alexandria, Va.

Your Future in Solid Propellant Rocketry

Successful development of a solid propellant rocket is possible only through successful team research. The following examples are some of the major career opportunities you will find among the many interlinked requirements of the team effort.

• *As a chemist,* you must create practical fuel systems of high energy and develop adequate ballistic properties through catalysts and formulation to meet a wide range of performance and environmental needs. . . .

• *As a materials specialist,* you must look to propellant structural requirements to withstand ignition-pressure stresses and high-acceleration launching and flight. You must provide a propellant with good mechanical properties for service from −65 to +150°F, or +200°F, or higher, and employ rocket motor materials exposed to 5000°F gases flowing at sonic speeds. . . .

• *As a physicist,* you must measure pressures, temperatures, thrusts, and other parameters, and devise control devices that record or control phenomena that change significantly in milliseconds or faster. . . .

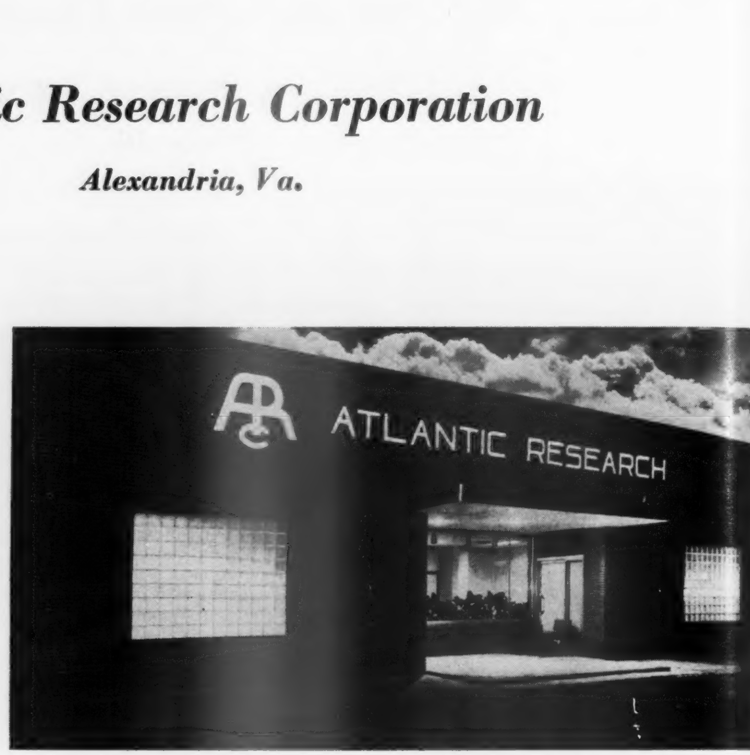
• *As a mathematician,* you must develop fuel shapes that burn to produce propellant gases at prescheduled rates, and reduce the need for very costly experimentation through full use of physical science theory and mathematical technique. . . .

• *As a process engineer,* you must develop effective processes for manufacturing propellants and rockets safely, economically, and with close quality control. . .

• *As a rocket designer,* you must combine ballistic, metallurgical, and fabrication know-how to turn out a product combining the close stress tolerances typical of aircraft design, with heat release and heat flow rates exceeding those of a nuclear reactor. . . .

A high order of technological skill is required to integrate these specialized capabilities into a successful team development. As a member of such a group, you will learn some of these team research techniques at first hand. The team research technique has been a "breakthrough" in the modern technologist's abilities to exploit scientific knowledge. Experience with a team research effort will be professionally valuable to you.

Because so many of the phenomena associated with rockets are on the technical frontier, the work offers you rich opportunities within your chosen scientific field. Usually, you will find opportunities to apply the full range of your technical capabilities—mathematical, mechanical, chemical, and so on—when you are working in solid propellant rocketry.



ARC'S home office is ten minutes from Washington National Airport

Your Future at Atlantic Research

Atlantic Research Corporation's program in rockets and propellants has broadened and enlarged over the years, largely because of technical contributions resulting from our development program. Our current activities provide a range of career opportunities in solid propellant rocketry and associated work that is indicated by the following:

- Combustion research
- Theoretical and mathematical studies
- Laboratory research on new propellant systems
- Rocket and gas generator prototype development
- Propellant pilot plant process development
- Intermediate-scale propellant production

Our charter imposes no restraint should full-scale rocket manufacture later prove desirable.

In addition, many other company activities, not related to rockets directly, are comparable in their technical demands. In number, though not in dollar volume, the company has conducted more projects in non-rocket fields than in rocketry. The following nonrocket projects illustrate the broad range of applied science project activities the organization is equipped to carry out, and suggests the opportunities open to the creative research worker:

- Synthesis of natural rubber by fungi
- Survey of Diesel engine operation at low temperatures
- Evaluation and development of bottle cap liners
- Improvement of oil-well perforation equipment
- High-speed wind tunnel design services

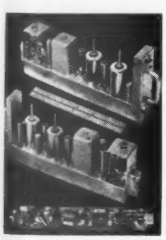
- Development of commercial instruments for measuring dynamic shear modulus of viscoelastic materials
- Development of improved piezoelectric air-blast gages and transducers
- Establishment of technical library programs, including floor plans, equipment, and staffing.

In a very real sense, a pronounced climate of individual opportunity prevails in Atlantic Research. It rests on a record of rapid organizational growth during which the company has been successful in most of its undertakings. Technically productive scientists and engineers constitute the top management of the company. Company policies favor the creative technical man.

The Organizational Background

Atlantic Research was founded by Arch C. Scurlock, a chemical engineer, and Arthur W. Sloan, an organic chemist, in 1949. The company first opened its doors for business on January 24 of that year with a total capital of one thousand dollars and a staff of the two founders. From that start, the organization grew steadily and rapidly. Financially, it has remained in the black since its beginning.

Present staff totals approximately 150, about a third of whom are graduate scientists and engineers, and the company is now doing research and development work at a rate of approximately one and a half million dollars a year. The organization currently occupies nearly 50,000 square feet of office and laboratory space in four Alexandria buildings just across the Potomac River from Washington, D. C. The other major installation consists of a large pilot plant and other experimental facilities on a 588-acre tract near Gainesville, Va., 35 miles southwest of Alexandria.



A custom subminiature amplifier for a missile - tracking computer circuit

The organization is financially independent, stock being sold only to employees.

The company's growth is an interesting study in boot-strap levitation. Originally launched with jet propulsion the dominant theme, our program soon required the assembly of a wide range of key skills. Once the key specialists had arrived in the organization to serve the propulsion activity, they began to generate other programs centered on their technical specialties. Through this means substantial activity has developed in advanced instrumentation, applied mathematics and interior ballistics, and fluid dynamics and combustion research, to name three examples. In several instances, most notably in acoustic instrumentation, successful project work in these areas has led to products the company now manufactures and markets. The growth of these other skill areas has greatly enlarged the resources in staff and facilities that can be drawn upon in the company's propellant and rocket developments.

At the present time, Atlantic Research Corporation has a broad-gaged program in applied science research and engineering development. In this respect, it is typical of a class of organization that has appeared in significant numbers the past decade to meet the requirements of modern industrial and defense technology. Atlantic Research's management thinks that the organization is just beginning to reveal its potentialities, and is both optimistic and ambitious regarding the future.

Gun barrel gage for peak pressures above 125,000 lb/sq in. with a rise time of 5 microsec

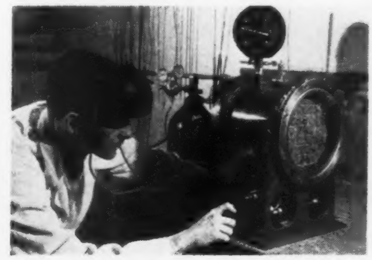
Technical capability is considered to be the key factor required for further success, and the effects of this philosophy are evident in the present staff and facilities. The technical staff of scientists and engineers averages 1.6 college degrees per person, and contains among its members persons who have received national recognition in their professional specialties. Selective efforts are made in recruiting new staff to find persons capable of applying basic science imaginatively and resourcefully in solving practical problems.

In facilities, the emphasis on functionality is also evident. Few "marble palace" laboratory rooms are in evidence, but advanced equipment is obtained when needed for the requisite accuracy in project work. Individual offices for technical staff members are also provided, in the belief that the professional functions at his best when he can plan and evaluate his work in private.

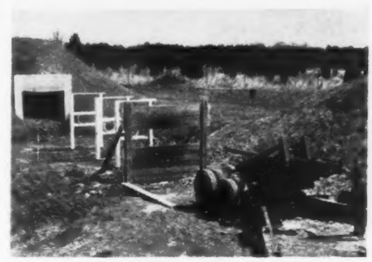
* * *

If you are interested in exploring specific career opportunities available at Atlantic Research Corporation, write or call. Your inquiry will receive prompt and thorough attention.

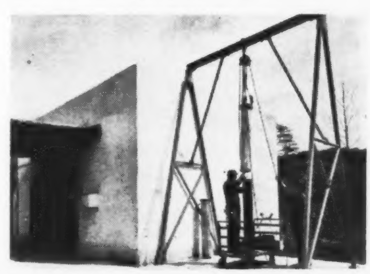
***Chemistry* . . . propellants, combustion, polymers, synthesis**



***Instrumentation* . . . quick-response, low-noise, acoustic, custom electronics**



***Ballistics* . . . of guns, rockets, catapults, cartridge-operated devices**



***Engineering* . . . propellant processing, rocket design, prototype development**

Our Experimental Field Plant includes solid propellant processing facilities and rocket assembly and test areas (shown here), a gun range, and other field installations. Room for future expansion is ample on the 588-acre tract

Battelle Institute

505 King Avenue, Columbus 1, Ohio

AS ONE of the world's largest independent research organizations, Battelle offers career opportunities in nearly all the sciences and technologies related to rocket and missile development.

Permanent staff openings are available for qualified aeronautical, mechanical, electronic, chemical, and design engineers. Attractive positions are also available for chemists, physicists, metallurgists, mathematicians, and computer technologists who would like to specialize in research in the fuels, materials, and control problems associated with flight vehicles.

At Battelle, you can virtually take your pick of research areas—and even of projects. You may choose engineering development, pilot-plant work, or bench-scale research. Or, should you prefer, you may concentrate on theoretical studies. Serving both industry and Government, Battelle interests are varied and ever-expanding.

Battelle does nothing but research—and this is one of its big advantages to a research careerist. Should you enter some phase of Battelle's research related to rockets or missiles, and later wish to change to, say, atomic power plant engineering, industrial product or process development, or consumer product research, the transition could be readily made.

Battelle works in all the industrially useful physical sciences, many agricultural and biological sciences, and numerous highly specialized technologies. Each year more than 1000 research projects are conducted in the Institute's laboratories in Columbus; Frankfurt, Germany; and Geneva, Switzerland. The 2800 scientists, engineers, technologists, technicians, and service personnel associated with Battelle will be responsible for $19,000,000 in research expenditures this year.

To encourage professional development, Battelle provides a free working environment. You, as a beginner on the Battelle staff, will work side-by-side with prominent technologists, with whom you will be on a first-name basis. You will be given an assignment and suggestions for its execution, but no strict regimen will be laid down for you to follow. At every point, you will be encouraged to think for yourself—to make suggestions—to ask questions—to join in the team operation as a full-fledged member.

You will be given every opportunity to write technical papers, to participate in the committee work and meetings of technical societies, and to pursue your professional studies. Should you wish to take postgraduate work at nearby Ohio State University, Battelle will reschedule your working time and *pay your matriculation and tuition fees.*

Battelle conducts quality research and has a worldwide reputation for integrity and accomplishment. Since the Institute's founding in 1929, it has grown almost continuously, and its management has a strong growth philosophy. Indicative of this philosophy is Battelle's recent construction of the first complete, private center for atomic research.

Because Battelle is a growing organization, opportunities for promotion are great. And, you can take your choice between advancement into managerial positions or advancement into posts of technical distinction.

Salaries are in keeping with going rates, and promotions and salary increases are on a merit basis. All the customary social, recreational, and health services are available. The Institute's insurance and retirement plan is recognized as one of the best in the nation and will provide you and your family exceptional financial security. Metropolitan Columbus, a city of 610,000 is geared to the likes and interests of professional people.

To become a member of a research organization that is known throughout the world—that is a leader and a pioneer—that can offer you a permanent and satisfying career, write to Mr. R. S. Drum, Personnel Manager.

Battelle's central laboratories in Columbus house more than 17 acres of research facilities. New atomic energy laboratories are situated on a 400-acre tract in the suburban area

Bulova Research and Development Laboratories

62-10 Woodside Avenue   Woodside 77, N. Y.

THE Bulova Research and Development Laboratories, a wholly owned subsidiary of the Bulova Watch Co., was organized in 1950 in order to intensify and diversify Bulova's World War II development and production experience in airborne instrumentation and antiaircraft artillery fuses.

Within this brief period, Bulova has concentrated on making significant contributions to the nation's defense, primarily in the field of precision airborne equipment, where high accuracy functional performance must be provided at minimum weight and volume. These achievements include: mechanical and electromechanical fuses for shells, bombs, rockets, and guided missiles; guided missile safety and arming devices; solid propellant actuated miniature guided missile gyros; airborne camera systems and automatic aperture controls; a precision closed-loop altimeter; and an electromechanical fire control system for launching surface-to-air missiles. In addition, Bulova is contributing to the National Preparedness Program by virtue of: (i) a multi-million dollar automation research and development program wherein a reappraisal of the entire process for the manufacture of quartz crystals has been undertaken for the Signal Corps; and (ii) the development of production line techniques for infrared sensing and other solid state physics devices suitable for missile guidance applications.

● Of special interest to readers of this ARS supplement should be the recent formation by Bulova of an Advanced Systems Department for the purpose of conducting research and development in the field of guided missiles and in the field of complex electronic systems having military or commercial applications. While this advanced systems effort is new, it is organized around a central group of engineers having considerable prior experience of successfully working together as a team on government sponsored missile systems projects. Its growth and success are assured by the proficiency of the Bulova organization in low cost, high precision manufacturing techniques, the experience of other Bulova departments with advanced electronic or electromechanical components, and by virtue of its ready access to the extensive laboratory, experimental shop, and production facilities of the parent organization.

Since its inception early in 1955, the Advanced Systems Department has centered its activities in the field of small bore guided rockets and guided missiles incorporating simple and novel guidance techniques. These efforts have borne fruit in the form of a contract for the study of an advanced small bore missile system for the Department of the Army involving the full gamut of missile technology: guidance, control, aerodynamics, jet propulsion, operations research, etc. In addition, the Advanced Systems Department has placed auxiliary emphasis in its preparation of technical proposals on astutely engineered electronic systems epitomized by navaid, fire control, and simulator equipments. One result of these efforts is an extensive study of advanced electromagnetic homing techniques which is now under way.

System synthesis and analysis work performed under the above contracts is predicated on a combination of the latest rocket and missile technology with an optimal use of statistics, decision theory, gaming methods, etc., together with thorough studies of the operational situation, in order to assure systems which are optimum on the basis of cost-effectiveness considerations and their ability to be efficiently integrated into existing or projected military environment. To assure maximum utilization of the experience and talents of each individual, judicious and successful use is being made of the precepts of group creative thinking.

● The activities of the Advanced Systems Department are now expanding at an ever-accelerating pace, primarily in the above-mentioned project areas. This will require the addition of engineers and scientists interested in applying the very latest techniques to the synthesis, analysis, and development of novel and operationally optimum missile systems. The opportunities for advancement and professional development at Bulova in general, and in its Advanced Systems Department in particular, are sincerely deemed to be exemplary: it is a young and dynamic organization; it is led by a core of progressive, professional-minded veterans of the missile business; and provides, it is believed, the only opportunity to work on a prime advanced missile systems project in New York City. Here extensive opportunities for advanced study are available at Columbia University, New York University, The Brooklyn Polytechnic Institute, Cooper Union, etc., while active participation in the affairs of professional societies is facilitated by virtue of headquarters' location here and the concomitant concentration of national meetings and symposia. Bulova's professional advancement program provides for tuition reimbursement to individuals successfully completing work-related university courses during employment.

The Advanced Systems Department, shown here in a typical problem-solving conference, requires for its immediate expansion specialists in infrared techniques, microwave propagation, circuit theory, operations research, and missile design

The University of Chicago

Chicago Midway Laboratories

6220 S. Drexel Ave., Chicago 37, Ill.

Facilities

CML is an organization devoted to research and development work for the Armed Services. As CML is a part of the University of Chicago, its personnel and equipment are supplemented by the excellent facilities of the University and by its own test crew and prototype shop. Approximately 150 scientists and engineers make up the organization. This is an optimum size for the young engineer: large enough to supply the opportunity to work with and learn from experts in his field, and small enough to provide opportunity for advancement.

In addition to rocket and missile research and development, CML is engaged in research and application of infrared, electronics, systems evaluation, etc. Activity at this laboratory will continue as long range activity of the university.

Employment

Employment by CML is a rewarding experience which enables the young engineer to enjoy the rich surroundings of the University of Chicago and the stimulating environment of the city itself.

Within the Laboratories, challenging and diversified projects are assigned to small groups under the leadership of an experienced scientist. Those within the group become familiar with all aspects of the project. Promotions are granted on the basis of merit rather than seniority, and the corresponding increases in salary are liberal.

Openings

Chicago Midway Laboratories offers exceptional career opportunities to competent and energetic men with good theoretical and applied backgrounds at all levels in the following areas:

Aerodynamics
Fire control systems design
Optics
Engineering Mechanics
Infrared
Radar systems analysis
Solid state and vacuum tubes (PhD. essential)
Circuitry
Communications

Qualifications

Prospective employees must possess at least a bachelor's degree and be a citizen of the United States. Applications from graduating engineers are welcome.

Write for application blank or send résumé to:

J. A. Sinclitico, jr.
Chicago Midway Laboratories
6220 So. Drexel Ave.
Chicago 37, Illinois

or call BUtterfield 8-6625 in Chicago.

Additional Opportunities

The University is an excellent institution for advanced education in your chosen, or related, field or in business management, with remission of tuition provided.

In addition to excellent salaries and educational opportunites, CML fringe benefits include a month's vacation, sick leave with pay, life and hospitalization insurance, and a generous retirement plan.

Living Conditions

The size of metropolitan Chicago guarantees excellent living conditions for all employees. The unmarried engineer can be housed in any of many facilities on or off the campus. The married man may choose to enjoy suburban life in the new village of Park Forest, which affords excellent housing and social activity at moderate cost, or one of the many other towns surrounding Chicago.

The Laboratories sponsors many social and athletic activities including bowling and softball leagues, golfing tournaments, picnics, and dances. Use of the various gymnasiums and athletic fields of the University are also available to employees at no cost.

Snark SM-62—First U.S. intercontinental guided missile to be unveiled by the U.S. Air Force

Curtiss-Wright Corporation

Wood-Ridge, N. J.

Curtiss-Wright Today

THOUGH best known for its important role in the nation's defense, Curtiss-Wright actually serves many different fields ranging from nuclear research to plastics. 28,000 employees in 15 divisions now produce over $500 million worth of goods a year.

Curtiss-Wright Tomorrow

The finest and most modern facilities for research, development, and production are in use right now at Curtiss-Wright. (Only by having every modern resource today can tomorrow's fullest potential be realized.) For example, Quehanna—a tremendous new research and development center, 80 square miles in size—has just been opened in north central Pennsylvania. Here—and in other Curtiss-Wright communities—creative engineers, technicians, and scientists find the resources, associations, and attitudes that encourage their best work, and turn new ideas into new accomplishments faster.

Rocket and Missile Activity

Curtiss-Wright is the only company producing *every type* of power plant used for propulsion of aircraft and guided missiles. It is the oldest source of aircraft engines in the U.S. Curtiss-Wright can power any type of flying vehicle with its rockets, ramjets, turbojets, turboprops, and reciprocating engines.

A Few Achievements

The Turbo Compound is the leading airline power plant in use today. The J65 turbojet powers many of our military aircraft. Ram jets power the Navaho Missile. Throttling rocket power plants are used for the Bell X-2 high altitude supersonic research airplane. These are but a few of the products developed and produced by Curtiss-Wright.

Continual Pioneering

Since 1912, Curtiss-Wright has developed new or larger markets by introducing basic product improvements with its products. This will continue to be the Curtiss-Wright philosophy. Forecasts for the next twenty years indicate further expansion for every one of the company's divisions.

More Research, More Growth

Curtiss-Wright is properly "research minded," for today's research is tomorrow's achievement. In addition to exceptional research programs in each division, Curtiss-Wright has a separate division devoted primarily to basic research.

Every Opportunity

Because Curtiss-Wright serves so many different markets, there are opportunities of all kinds for good scientists and engineers, whatever their career backgrounds or inclinations. Design, development, research, test. . .administration, sales, service. . .corporate, plant, or production management—name your talent and find your career at Curtiss-Wright.

Advancement Encouraged

A policy of frequent reviews makes certain that each individual moves on as he qualifies for promotion and higher earnings. The Curtiss-Wright pay scale for technical and managerial employees is one of the industry's highest.

Management Training

An active training program further develops all supervisory, administrative, and professional employees with a noteworthy management development program. It is under the guidance of experienced consultants. In addition, Curtiss-Wright encourages continuation of studies with a special tuition-refund program.

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Better Living

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Experiment Incorporated

Richmond 2, Virginia

HISTORY IS BEING MADE

Young and growing, Experiment Incorporated has been making history for over eleven years in the development of propulsion systems for guided missiles; in the development of both solid and liquid propellants; and in basic research on combustion, high energy fuels, and related chemical processes.

Instrumentation and controls at rocket test facility

Experiment Incorporated has pioneered in:

GAS GENERATORS

SPECIAL ROCKETS

AIR TURBOROCKETS

MONOPROPELLANT RAMROCKETS

LIQUID AND SOLID FUEL RAMJETS

A solid fuel ramjet test vehicle just prior to flight testing

In these and other activities, Experiment offers outstanding opportunities to engineers and scientists interested in a challenging future.

For information on our operations, modern facilities, and the complete EI story, ask for our descriptive brochure.

Write to: Personnel Manager, Experiment Incorporated
Richmond 2, Va.

Administration building . . . the control center of activities

Fairchild Engine Division

A Division of Fairchild Engine and Airplane Corporation

Deer Park, Long Island, N. Y.

Fairchild Engine Division at Deer Park, Long Island, N. Y., is one of the nation's leading producers of jet engines and jet engine components, and pioneer in research, development and production of small, lightweight jet engines.

Its range of activities includes power plants for inhabited and uninhabited aircraft; major components for jet engines, and underwater weapons such as the U. S. Navy's new X-1 midget sub.

An extensive new facility at Deer Park has recently gone into operation. It comprises a new plant and a Gas Turbine Laboratory providing those in advanced engine research and development with the most modern equipment available. Present projects involve new small jet engines for many applications; radical new propulsion systems, fuels, designs, etc., for use by both the Armed Forces and the commercial aviation industry.

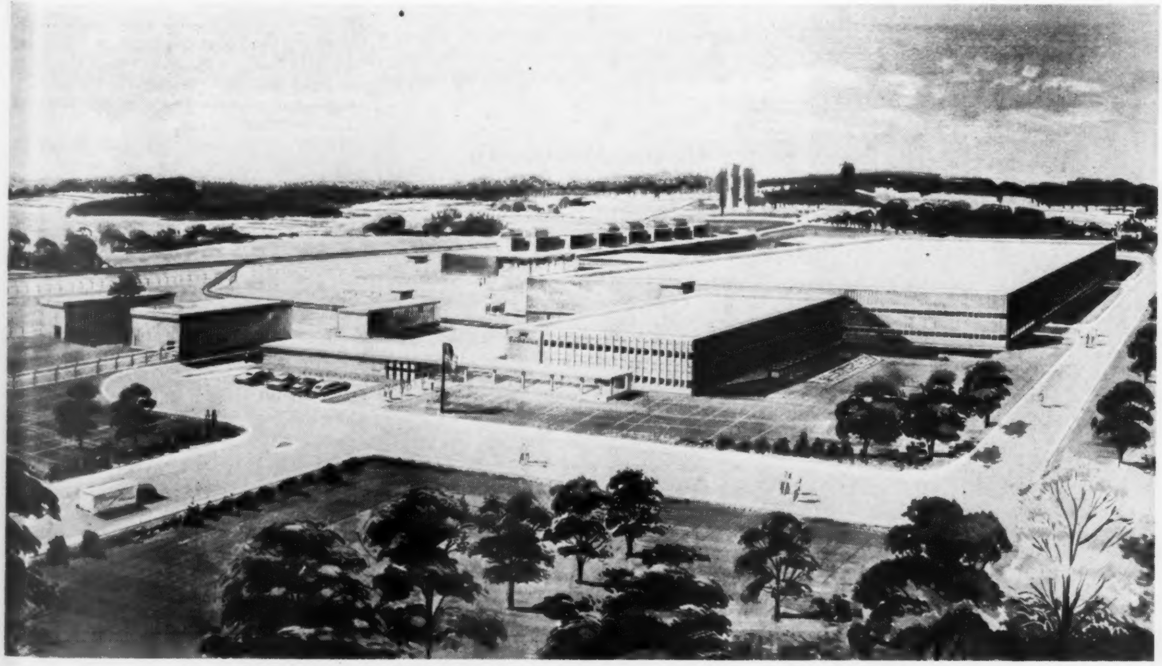
New Fairchild Gas Turbine Laboratory incorporates the latest and most advanced equipment

These expanding programs insure more than just the basic opportunities for both the young and the experienced engineer. And, the company's approximately 30 years of constant progress in all phases of power plant development and manufacturing are reflected in its modern personnel policies and practices, which include many well-directed programs, such as internal training and orientation, and ample opportunity for educational progression.

Liberal noncontributory pension plans as well as better-than-average health and life insurance benefits are provided. Most important, Fairchild Engine Division applies its policies and benefits to assure each employee personal attention.

Living conditions in Long Island are excellent. Low-cost attractive housing is available; good schools, hospitals, and shopping centers are conveniently located.

Metropolitan New York is close by and virtually every sort of recreational facility is readily available—golfing, swimming, fishing, boating, riding.



Fairchild Engine Division's new home for power at Deer Park, Long Island

Ford Instrument Company

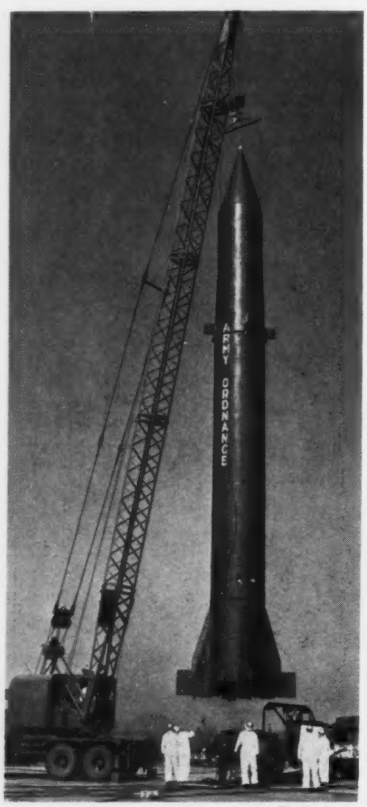
Division of Sperry Rand Corporation

31-10 Thomson Avenue, Long Island City, N. Y

Missile Guidance

FOR several years the Ford Instrument Company has been working on a number of phases of missile guidance, and in particular on guidance systems for ballistic missiles. In this category, working closely with the United States Army Ordnance personnel at Redstone Arsenal in Huntsville, Ala., the engineers of Ford have been busy on improvements in the guidance system of the Redstone Missile. At present the company is in the production and product engineering phase of this project.

Under the new Army Ballistic Missile Agency a new program has been set up for the development of advanced missiles of greater range, and Ford Instrument Company is preparing to increase its participation in the development of guidance systems. For that reason the company has established a new Missile Development Division. These top-priority programs will require considerable expansion in many types of personnel and facilities.



U. S. Army

Redstone Ballistic Missile, progenitor of more advanced missiles. Ford engineers helped develop and design the missile's guidance system

Expanding Facilities

Under the new organization the manufacture of parts and final assembly on the Redstone and other ballistic missile programs will be handled in the firm's two present buildings. A third building has been acquired to provide a place for all the engineering, development, experimental, and test facilities. This addition to the company's present laboratories and shops will give Ford Instrument Company one of the finest research, design, and manufacturing plants in the country.

In conjunction with this, the company is building a new gyroscope-test laboratory which will enable it to make further advances in a field in which it has been active for four decades.

Company Growth

Ford Instrument Company was founded in 1915 by the late Hannibal C. Ford, to develop, design, and build computers and controls for naval guns. Mr. Ford's inventions revolutionized naval warfare by introducing what is now called "automation" into ship gunfire control. As time went on, the company developed the first automatic computing antiaircraft gun director and a whole group of surface-fire computers, gun drives, torpedo guidance systems, and their related components.

In more recent years, Ford has been a leading company in the development of aircraft navigational systems, cruise control instruments for jet aircraft, various accurate timing devices, weapon control systems, and missile and rocket launching computers. It is under contract to the Army, the Navy, and the Air Force for many instruments which, due to their classified nature, cannot be discussed.

The instrumentation and controls for the atomic submarine, "Seawolf," were developed and built at Ford Instrument Company, and the engineers at Ford are currently busy on contracts with the AEC and have designed reactors for both a municipal power plant and a power plant of an ocean-going tanker.

Only eight years out of engineering school, Lewis Scheuer has risen to the newly created position of Director of Engineering of the Missile Development Division

It is but natural that a company so experienced in precision equipment, control, computing, and sensing devices should enter the missile guidance field. Its work with the engineers at the Redstone Arsenal for the past number of years has enabled Ford to become one of the most experienced companies in the country on ballistic missile guidance systems.

The company is a division of the great Sperry Rand Corporation, one of the outstanding organizations in the world in the field of computers, electronics, controls, and other such highly engineered equipment.

Opportunities at Ford

With the formation of the new Missile Development Division, a great many opportunities are opened for capable engineers. The program of enlarging this department steadily during the next several years will give engineers an opportunity to advance with the growth of the new division.

The company has an enviable record. Since its founding in 1915, Ford Instrument Company has never terminated a competent development engineer because of lack of work, and we will continue to maintain this record.

Our company has always promoted from within. Our President and our Chief Engineer as well as other top executives started their careers as Engineers with the company. This promotion policy shows a ready recognition of ability and initiative.

Engineers find that work with Ford Instrument Company offers many advantages. Working in small teams on specific projects allows each man to increase his personal knowledge as he works closely with other engineers and participates in conferences on over-all problems with specialists in various fields. He also is in a position to receive personal recognition for his own work.

There is the additional satisfaction of seeing the work he is doing through from initial theory to finished product.

The company employs about 2500 people of whom 500 are development, test, and production engineers.

Engineers Needed

At present the new Missile Development Division is looking for electrical engineers, mechanical engineers, test engineers, and field service engineers, in the research and development as well as the production and product engineering phase.

Bachelors, Masters, and Doctors in engineering or men whose background, training, and work experience would qualify them for the work being done are being sought. Applicants must have an interest in and capabilities for research and development, for learning new techniques and skills, for advancing with the future advances made in control engineering.

Salaries are commensurate with a man's education, experience, and abilities, and are reviewed every three months to determine whether a man may be raised to a higher salary or to a higher job classification.

Most of the work will be done at the home plant of the company. However, after an indoctrination period, a number of engineers and field service personnel will be assigned to the company's laboratories at the Redstone Arsenal in Huntsville, Ala., and some will go to Patrick Air Force Base test center in Florida.

Benefits

In addition to the regular salaries, Ford provides for the financial security of its employees and their families in many other ways, amounting to more than 25 per cent over his quoted salary. The company pays three quarters of the Accident and Sickness Insurance and the entire expense of: Retirement Pension Plan; Sick Leave Pay; Hospitalization; Surgical Benefits (40 per cent over Standard Blue Shield); In-Hospital Medical Benefits (50 per cent over standard); Group Life and Disability Insurance; nine full and two half-day holidays and two weeks' vacation (after 10 months' employment). Besides these, the company has thorough free health examinations for all employees who desire them, and the company will refund the cost of tuition for any advanced courses of study and one half the membership dues for one engineering or scientific society.

The plant location within fifteen minutes of the heart of New York City allows its employees many benefits. Not only are there fourteen colleges and universities in the area (for an engineer or his family to attend) but also theaters, music, sports, museums, and other attractions of America's Number One city readily available. Within a few hours the boating, swimming, and fishing of the Atlantic coast, the golf, tennis, skiing, and hunting of New England and Long Island can be reached. Most of our employees live with their families in the suburban fringes of the city.

Other Opportunities

Besides the work to be done by the new Missile Development Division at Ford Instrument Company and which is a program extending many years into the future, there are many other activities in the plant which offer opportunities to engineers and physicists.

Other missile guidance programs besides that of ballistic missiles are being worked upon also. Ford developed and built the launching computer for the Terrier Missile as installed on the *USS Boston* and *Canberra.* Special projects demanding talents in servomechanisms, data processing design, gunfire control, and aircraft instrumentation call for additional engineers now and in the future.

Increasingly strict environmental conditions for equipment used in this supersonic age calls for the design of special test equipment, the ability to direct elaborate shock, acceleration, temperature, and other tests of all components and systems. Engineering writers capable of preparing engineering reports, operation and maintenance manuals or instruction courses also have a future at Ford.

Due to the nature of the company's work, all engineers must be able within a reasonable time to obtain and retain a security clearance required to work on military equipment.

Write in Today

If you are interested in a career in the field of missile guidance or in weapon control work—if you feel that your abilities and training qualify you for this work, write to Philip F. McCaffrey at the Ford Instrument Company, Division of Sperry Rand Corporation, 31-10 Thomson Avenue, Long Island City 1, N. Y. He will send you all information and let you know how an interview may be arranged. There is a future for capable engineers at Ford.

Ford Instrument Company engineers measuring drift rate of gyros through an auto-collimator and checking magnetic amplifier components for a missile guidance system

Checking voltage and frequency accuracy of a power supply unit under simulated load conditions for a guidance system being developed for the Army Ballistic Missile Agency

Firestone Tire and Rubber Company

Guided Missile Division

2525 Firestone Blvd., Los Angeles 54, Calif.

Organization

THE Firestone Tire and Rubber Company for many years has held a position of leadership in weapons research and manufacture. Engineering and production achievements at Firestone's defense products facilities have included 90-mm tank cannon, 3-inch 0.50 caliber naval guns, 40-mm antiaircraft batteries, 106-mm recoilless artillery weapons, and troop-carrying gliders.

A wide scope of engineering activities at Firestone's Guided Missile Division is devoted to America's first operational ballistic missile, CORPORAL. Never-sleeping sentry for the nation, the CORPORAL is another example of the Firestone organization's leadership in design and manufacture of modern weapons systems.

Since Firestone accepted the challenge to produce the CORPORAL, engineering and development at the Guided Missile Division have demanded engineering personnel of the highest caliber. The Los Angeles site of the Guided Missile Division was enlarged in 1955 by the construction of a multi-million dollar factory and engineering facility.

Guided Missile Division activities are supported by the financial and managerial resources of the entire Firestone organization, a leader in American industry and research since its founding in 1900.

The Guided Missile Division provides complete facilities for the development, engineering, fabrication, and evaluation of prototypes, and the production of resultant designs.

A new multi-million dollar facility in Los Angeles was constructed in 1955 to house the Guided Missile Division

Activities

Unlimited opportunity exists in the Guided Missile Division for engineers and recent engineering graduates. The professional development of each engineer is encouraged at Firestone, and is limited only by the capability of the individual to learn and by his ability to utilize his basic engineering education.

Projects now under way in the Guided Missile Division include studies in flight simulation, environmental and flight testing of missile components, and the design of automatic test consoles for electronic equipment. Engineering effort is being expended on all phases of electronic component and circuit design, miniaturization processes, and in techniques of missile guidance. Studies are being conducted in automation and in computer research.

Engineers in the Guided Missile Division have challenging responsibility in many new developmental projects

In addition, electronic studies are under way in theoretical and applied systems, design of special test equipment, and systems analyses.

Engineers in the mechanical engineering sections are concerned with design, in providing reliable hardware and documents, and insuring economic production for the Corporal system. Structures, ground support equipment, propulsion, materials, and prototyping are included among the many projects conducted in this engineering phase. Involved fields include stress analysis, hydraulics, pneumatics, aeroelastics, thermo- and aerodynamics, metallurgy, and plastics research.

Broad technical and laboratory facilities are the keynote of an aggressive research organization, and at Firestone these facilities are exemplary.

Training

Firestone engineer-trainees receive comprehensive instruction in all phases of missile characteristics

Integrated training programs for professional and managerial advancement are a vital part of the Guided Missile Division's engineering effort. From the day each new engineer joins Firestone, he is given orientation by, and works with, qualified and experienced engineers.

Firestone's comprehensive engineering training program for recent college graduates includes extensive classroom training, followed by rotating assignments within the division. Classroom work, in combining lecture courses on the electronic and mechanical characteristics of missile systems with practical demonstrations of these principles, aids in preparing the young engineer for the diversity of assignments he may be given in the engineering department.

In the on-the-job phase of Firestone training, the engineering trainee is guided by experienced engineers and is given responsible assignments as soon as possible compatible with the degree of problem complexity and the capabilities of the individual. This training plan is designed to provide each engineer with an assignment, after training, in which he can best utilize his talents and his capabilities.

Academic training also is available through the Guided Missile Division. Located in the Los Angeles area are the California Institute of Technology, the University of Southern California, and the University of California at Los Angeles; Firestone's employee advancement program provides for tuition reimbursement to employees successfully completing university and college courses during their employment.

General Electric Company

Rocket & Jet Engine Development Center

Cincinnati, Ohio

HERE'S an opportunity to join an expert Rocket Team that's pioneered many improvements in rocket engines since GE ran the first U. S. tests on the German V-2 engines in 1947. And an opportunity to enter a new field that's just coming into its own.

$100,000,000 Facilities to Work With

You'll have the most advanced privately-owned propulsion laboratory in the world to aid you. The General Electric Company has in full operation today, at the Evendale Development Center, facilities and equipment valued at more than $100,000,000—all built and equipped since the beginning of 1950. And more than half of this investment is exclusively in research, development, and test facilities.

Advanced Engineering

Rocket engineering is advanced in every sense—stimulating, demanding, tough, and immensely rewarding to able men. You can rise fast and go far in Rocket Development at GE. And the company will help you all the way.

Rotating Assignment Plan

GE acquaints engineers joining the Rocket Section with all phases of the work (research, design, development, and test). These appointments are WORKING ASSIGNMENTS in various sections, lasting about four months each. They may be interrupted at any time by a PERMANENT assignment, if a man decides early on his major field of interest. Salaries for engineers entering the ROTATING ASSIGNMENT PROGRAM are not set at any one figure, but depend upon educational background and previous experience.

Full Tuition Refund Plan for Graduate Study

Speeding the professional development of its professional staff is a definite GE policy, practically expressed through individual counselling, technical seminars, a Full Tuition Refund Plan for graduate study leading to advanced degrees (on an incentive basis). Participation in professional meetings and presentation of technical papers is encouraged with AGT—GE paying necessary expenses.

Association with Authorities in Rocket Engineering

. . .But the most important "educational" assistance of all that the company furnishes young professional men is CONTACT WITH GE'S EXPERT ROCKET TEAM. Men work here in small groups with frequent consultation available with recognized authorities in this pioneer field.

Extra Advantages Every GE Engineer and Scientist Enjoys

These include respect and appreciation of his professional status with competent assistants doing the routine work. Salaries are high and based on experience, education, and performance.

Openings for Graduates

. . .Design and develop rocket engine valves, seals, and piping. Establish and maintain standards and instruction for their manufacture, test, installation, and operation.

. . .Design, develop, construct, and test rocket engine seals and piping. Prepare standards and instructions for their manufacture, test, and use.

. . .Assemble and test rocket engines from their functional components. Design and develop supporting members needed to mount engine components.

. . .Design, develop, construct, and test propellant pumps.

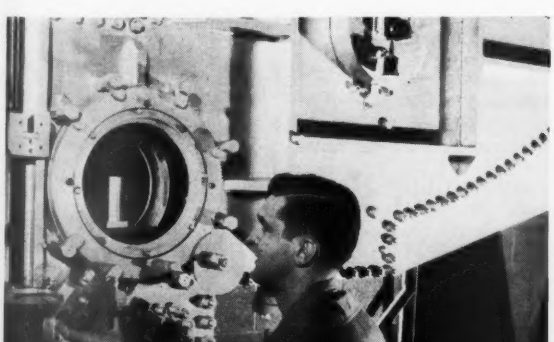
. . .Design, develop, construct, and test turbines. Conduct performance analysis.

. . .Create designs for high performance rockets; provide data on aerodynamic design and performance, and conduct theoretical and experimental investigations of designs created.

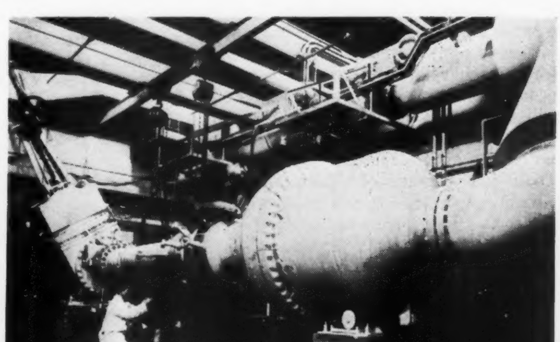
Openings in both Malta, New York and Cincinnati, Ohio

For further information, please write to:

MR. BRUCE MATHEWS
Technical Recruiting Bldg. 100
Aircraft Gas Turbine Division
General Electric Co.
Cincinnati 15, Ohio



PORTHOLE TO TOMORROW. This new supersonic wind tunnel has been installed at the General Electric Company's Development Laboratory at Evendale, Ohio, to work on tomorrow's problems in the rocket and jet engine field. Air rushes through this tunnel at over 18,000 miles per hour.



COMBUSTION TEST CELL. One of General Electric's combustion test facilities, used to test new combustion systems for future rocket and jet engines. It is shown in the final stages of preparation prior to a burner test. The large tank in the foreground serves to straighten airflow for entrance into test section.

Grand Central Rocket Company

Box 111
Redlands, Calif.

Are You Bewildered?

BY NOW you have probably been drenched by a shower of job opportunities. Perhaps you feel inundated by the deluge of titles, positions, and fringe benefits offered by the larger organizations.

With your future at stake, you should give serious consideration to the size of the organization that you join. Perhaps you should think of the size of the organization as representing a common denominator and yourself representing the numerator. You may well be alarmed at the prospect of becoming a single drop in a very large bucket. We would like to discuss the advantages offered by a comparatively small but rapidly expanding organization.

We Offer Opportunity

We can offer you the opportunity to grow with a young and vigorous organization in a new and expanding industry.

You will receive extensive on-the-job training in the scientific, technical, or managerial field that you find of interest to you.

For example, we are currently working on the third-stage rocket for Vanguard.

You will have the opportunity to shoulder individual responsibility and to pursue many of your own ideas of conception to completion.

You will have opportunities for advancement which are limited only by your ability and your initiative.

You will have an opportunity to actively participate in research, development, and production programs of vital interest and extreme importance to the welfare of our country. This includes probing into exciting new frontiers in the fields of long-range missiles and satellites.

Career Potential

Grand Central offers future careers in all branches of engineering and the sciences. A balanced group of aerodynamists, mechanical and chemical engineers, structures engineers and physicists make our team capable of designing rocket motors from the broad systems viewpoint. Each project presents new challenges and new problems.

Although new applications of existing propellants have provided much of our business, Grand Central has made its basic research a paying proposition. We have answered the demand for larger power plants with successful designs from our own drawing-boards. We have met the challenge for higher performance propellants with proved new formulations now in use. Members of our team not only get valuable technical training on the job but have ample opportunity to grow in administrative skill as they coordinate the various phases of work on an assigned project.

In addition to the training inherent in research and development work, Grand Central is planning a program of formal accredited courses in all phases of rocketry.

A Growing Team

Grand Central Rocket Co. is a team of engineering, scientific, and production personnel managed by recognized leaders in the solid propellant rocket industry. The purpose of this team is to engage in applied research, development, and production of solid propellant power plants for all types of rocket applications. A major portion of effort is assigned to the design and development of high performance solid propellant rocket motors for missile propulsions systems.

Formed in 1952, Grand Central has since built and privately owns a new and modern facility designed specifically for production and testing of solid propellant rockets. The original plant capacity has been greatly increased by new construction this past year and we now have a new air-conditioned Administration Building under construction.

The present plant has been built in one corner of a 1000-acre site which assures us ample room for expansion. Our rapid growth is indicated by the fact that we have doubled our personnel to 150 employees this past year, and we expect to double in size again this year.

A Choice Location

Grand Central Rocket Co. is located in the most desirable part of Southern California. The plant is in a smog-free citrus area on the outskirts of Redlands, a city of twenty-thousand people. Redlands lies 65 miles east of Los Angeles at the foot of the San Bernardino Mountain Range. An hours drive will take you to the mountains, desert or beaches. Redlands is a fine residential city with excellent schools and many civic and cultural advantages. The University of Redlands and the University of California at Riverside provide opportunities for undergraduate and advanced study.

Summary

We believe that you will find unusual opportunities in a young dynamic organization. At Grand Central Rocket Co. we know that we can offer you these opportunities:

- The opportunity to work with one of of the best teams in the Rocket Industry.
- The opportunity to advance your training under recognized leaders in the field.
- The opportunity to develop a profitable and challenging career.
- The opportunity to advance rapidly with an expanding organization.
- The opportunity to live in one of the finest communities in Southern California.

These opportunities are available to Mechanical, Structural, Chemical, Aeronautical, Industrial, Electrical, and Civil Engineers; to Mathematicians, Metallurgists, and Physicist; to Technical Writers and Illustrators; and to graduates in the field of Business Administration.

Hughes Research and Development Laboratories

Office of Scientific Staff Relations

Culver City, Calif.

THE keystone to Hughes participation in the rocket propulsion field lies in the successful application of the weapons system concept for airborne guided missiles and their associated fire controls. In 1948 it was recognized that the power plant would play an essential part in the success of the over-all missile systems. Accordingly, a propulsion group was organized which, by working closely with the other missile designers of the Hughes team, could design and develop power plants to fulfill the highly specialized requirements of the airborne weapons system. Starting with a nucleus of a half dozen people, this propulsion activity has grown to a group of about 85. The Propulsion Department is one of the eight basic departments of the Guided Missile Laboratories. In a like period the Guided Missile Laboratories have grown correspondingly, increasing from less than 100 in 1948 to its present size of approximately 1400.

The guided missile is emerging as one of the most important weapons in America's defense arsenal. The Hughes guided missiles have been made possible by successfully combining the most advanced technology of electronics, mechanics, aerodynamics, and propulsion. The rocket motors developed by Hughes have successfully answered the demand for high-performance and reliable missile propulsion.

More specifically the propulsion group at Hughes initiates rocket motor designs and carries through the fabrication of experimental units, development testing under various environmental conditions, and release of drawings for production at the Manufacturing Division of Hughes Aircraft Company, at Tucson, Ariz. With solid propellant motors such as used for the Hughes-developed FALCON, a small air-to-air missile, support from other companies is relied upon for propellant development and loading operations. In this connection, important contributions have been made by several of the leading rocket manufacturers and laboratories. This diversified support permits continuing appraisal of the entire solid propellant industry by Hughes engineers.

Field testing is conducted at remote facilities such as USAF Holloman Air Force Base, Alamogordo, N. Mex.

All of the Hughes propulsion activities to date have been undertaken for the United States Air Force. The original version of the solid propellant rocket used for the Hughes FALCON is a specific example of the product of the Propulsion Department. Because of the practical demonstration of the feasibility of airborne guided missiles there is a constantly increasing demand for newer and higher performance rocket motors to propel the missiles of the future now in the planning stages. To accomplish these challenging tasks a professional team of approximately 30 engineers is required. This team consists primarily of men trained in mechanical, chemical, and aeronautical engineering. Imagination and initiative as well as technical training are vital factors in the successful development of rocket motors to fulfill the increasingly difficult propulsion requirements.

The propulsion activities are conducted at Hughes main Culver City plant which is located just 11 miles from downtown Los Angeles and within two miles of Santa Monica Bay. The surrounding area is zoned primarily for agricultural and residential purposes. The Hughes location is convenient to the University of California at Los Angeles, the University of Southern California, and the California Institute of Technology, for those engineers wishing to further their professional careers by taking after-hour courses. The cost of these courses is partially or completely reimbursed by Hughes, depending upon the circumstances. In addition, several courses are given at the Laboratories.

Exceptional opportunities are afforded by Hughes in their programs for advanced technical training. These are principally the Howard Hughes Fellowships for Doctorates at CalTech, and a Master of Science Cooperative Program at UCLA, USC, and CalTech. The Howard Hughes Fellowship has been established to aid in the training of outstanding research scientists and engineers in many fields, including propulsion. Each fellow is provided sufficient remuneration so that he can devote four-fifths of his time to his fellowship during the academic year, and during the summer months he devotes full time to the Hughes Laboratories. The Master of Science Cooperative Program is a two-year program. The student works full time at the Laboratories during the summer and part time during the university year. Master of Science degrees are awarded in such fields as electrical and mechanical engineering and physics, upon the successful completion of the two-year program.

In addition to the educational opportunities, many of the other employee benefits at Hughes are considered exceptional. Hughes pays the full premium on the employee's life insurance and testing and aviation insurance, as well as the workman's compensation and unemployment insurance. There are also attractive group insurance plans that can cover both the employee and his dependents. There is an attractive voluntary retirement plan. Other features of employee benefits are seven paid holidays per year and scheduled periodic reviews to assure that salary increases are in keeping with professional growth.

Those wishing to obtain further information concerning opportunities and professional careers at Hughes can do so by contacting the Office of Scientific Staff Relations, Hughes Aircraft Company, Culver City, Calif.

F-89H firing Hughes FALCON guided missiles

International Business Machines Corporation

590 Madison Avenue, New York City

This is an architect's drawing of IBM's new Airborne Computer Laboratory and manufacturing facilities, to be completed late this year at Oswego, N. Y. (Near Binghamton and Ithaca, N. Y.)

A Field as Big as the Sky—Airborne Computer Engineering

It seems likely that the future of flight guidance will, in large measure, evolve from the advances made in the development and design of airborne computers. For the aggressive and creative engineer, the airborne computer field holds an infinite potential—truly a field as big as the sky.

As an IBM engineer, in the Airborne Computers Laboratory, you'll have the opportunity to utilize facilities that rank among the finest in the world—in an atmosphere that stimulates and sustains engineering ingenuity. Here, at IBM, you can pioneer your ideas. To illustrate the point, IBM developed and is now producing the computing equipment for the navigational system, being used in the new Air Force B52's. Advanced projects of even greater importance are now underway, and they, too, require the knowledge, skill and originality of creative engineers.

If you possess experience in any one of the following areas: digital and analog computer circuitry and design...transistor circuitry...electronic display systems... microwave theory and wave guide design... component application and evaluation... electronic packaging...power supply design...servo and servo-control systems...optics...systems analysis and operations research...instrumentation theory and design...field engineering...then, *in terms of your professional growth*, you'd be wise to investigate IBM.

If interested, write, outlining your background and interests to: W. M. Hoyt, International Business Machines Corp., 590 Madison Avenue, New York 22, N. Y.

The M. W. Kellogg Company

A Subsidiary of Pullman Incorporated

711 Third Avenue, New York 17, N. Y.

Products Manufactured

High Strength Steel Rocket Cases for Navy Guided Missiles:

The M. W. Kellogg Company has been designing and fabricating rocket cases for the Navy Department since 1951. During this time, the company has pioneered in the development of propulsion equipment for most of today's ship-to-air guided missiles. The Terrier missile, for example, uses Kellogg designed and built booster rockets, as does the Talos Missile. Initial development has been carried out on a wide range of missiles, including the NIKE, Snark, Honest John, and Sparrow designs.

Scope of Company

The M. W. Kellogg Company's function in the design and manufacture of missile rocket cases is to prepare detailed working designs for extremely high strength steel structures. The rocket case is essentially a pressure vessel, and The M. W. Kellogg Company has pioneered in the development and manufacture of such vessels, using the highest strength materials known to engineering science.

In addition to its development and fabrication techniques, the Kellogg organization has been one of the leaders in the analytical study of these structures. The Kellogg analysis method is now used extensively in the industry.

M. W. Kellogg engineering has also pioneered in the development of reinforced plastic for these structures, using a unique filament winding method which produces structures of unparalleled accuracy and light weight.

Place of the Engineer

Engineering of rocket cases at M. W. Kellogg may be divided into four general categories, all related intimately to good mechanical and aeronautical engineering skills.

1. *Design Engineers:*

The design of rocket cases is a delicate balancing operation in which a structure is devised to behave like the traditional "one horse shay." The structure is designed so that ideally the breaking point is reached in all portions simultaneously. This is done to reduce weight to an absolute minimum. A designer requires skills in analysis of stresses, in fabrication and welding methods, in the use of high strength heat treated steels and, above all, a knowledge of the application of these steels to the guided missile—including external and internal ballistics.

2. *Project Engineering:*

The guided missile rocket is one part of a complicated assembly made by many different firms, all working through the Bureau of Ordnance of the Navy Department. Since these structures are usually developmental in nature, they are subject to a continuing series of design changes affecting mating parts, and an extensive project engineering program is continuously under way to assure that the parts as manufactured meet all of the detailed customer requirements. Project Engineering includes coordination with fabrication personnel and with the customer on a continuous basis.

3. *Manufacturing Engineering:*

The rocket business is entering a phase of its development in which experimental designs are being transformed into production pieces. The manufacturing or industrial engineer working on this program is faced with a host of challenging problems to improve producibility without sacrificing the high quality of product absolutely necessary in this case.

4. *Development Engineering:*

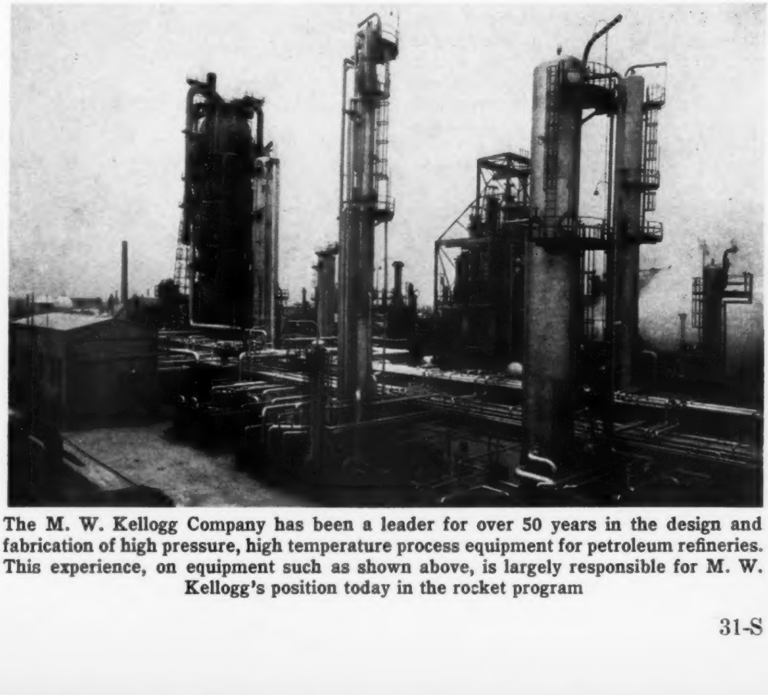
The rocket industry, along with the aircraft industry, is moving rapidly in the development of new materials of fabrication and methods of design. The development engineer at M. W. Kellogg requires an over-all knowledge of the problem, a knowledge of experimental methods and techniques, coupled with a solid background in mechanical and metallurgical engineering. The development engineer must be agile of imagination so that he may adapt himself to entirely new problems and programs, including the use of reinforced plastics and several novel methods of construction.

Company Location

M. W. Kellogg's rocket activity is currently located at its Jersey City plant near the heart of metropolitan New York City. Most Kellogg engineers live in suburban northern New Jersey. They are thus close to the cultural, educational, and recreational facilities of the world's largest city.

Employment Policy

In addition to the more or less standard provisions of retirement benefits, vacations with pay, group insurance, etc., the M. W. Kellogg Engineering Department offers to young engineers an opportunity to engage in a growing active business in which a variety of skills is required. This is particularly true of the Rocket Engineering Group. Being relatively small, it enables young engineers to receive individual attention in the development of their careers, and to participate in a number of different activities during their early years with the company to give them a broad background for future development. The salary policy of the company is liberal and conforms to the average in the industry.



The M. W. Kellogg Company has been a leader for over 50 years in the design and fabrication of high pressure, high temperature process equipment for petroleum refineries. This experience, on equipment such as shown above, is largely responsible for M. W. Kellogg's position today in the rocket program

Land-Air Incorporated

201 North Wells Street Chicago 6, Ill.

Scope

LAND-AIR, INC., was organized in 1946 and is a subsidiary of California Eastern Aviation, Inc. It consists of seven operating divisions with a roster of approximately 1600 employees. Executive offices are located in Chicago.

The company engages primarily in U. S. Government contracts, in avionics, electronic engineering, and manufacturing of electronic and electro-mechanical devices. The diversity of the fields covered by these contracts has enabled Land-Air to build an invaluable staff of experienced and highly specialized engineers and technicians. This strengthens Land-Air's position in entering non-governmental fields.

Land-Air participated in the establishment of the missile tracking operations at Holloman Air Force Base, New Mexico, in January, 1949. Since then, Land-Air has been under contract for the tracking of all guided missiles and drone aircraft operated from this test range. To carry out this mission, Land-Air has engaged in a research and development in the field of specialized optical and electronic devices used in range instrumentation.

The missile program led to the establishment of the Instrument and Electronic Division, an engineering laboratory and manufacturing facility at Oakland, Calif., where a staff of engineers, scientists, and technicians are doing "on the spot" functional fabrication of new equipment and new instrumentation techniques. Products of this division involve research, design, engineering, fabrication, servicing, and installation. They include a Time Signal Generator, which generates and transmits—by wire and radio link, a coded timing signal utilized in data collection equipment to provide the collation of data recorded. Other efforts have resulted in ultra-high speed cameras, telemetry, and specialized tracking devices such as the Orthogonal Coordinate Tracking Instrument. Subminiature radio receivers in a wide fixed frequency range and associated power supplies, each measuring 1″ × 3″ × 9″ were designed and are currently being manufactured by this division.

The Cheyenne, Wyo., Division designs, engineers, and prototypes the installation of electronic equipment in Air Force and Navy aircraft. These functions are primarily associated with electronic countermeasures, radar, communication, and navigation electronic equipment. In addition, this division effects modifications of military planes in production quantities.

The Chicago Manufacturing Division produces electronic modification kits for installation of communication, navigation, and identification equipment. These kits contain all required parts to permit installation in an aircraft located at its normal operating base. This division also produces aircraft engine analyzers which are used in military and commercial aircraft for guidance in observing and defining internal malfunctions of engines.

Field Operations Division, headquartered in Chicago, furnishes field crews specializing in electronic equipment installation to the Air Force and Navy. Installation crews operate from Air Force Bases in the United States and at overseas locations. This division has also designed and installed electronic communication equipment for the Corps of Engineers and the National Park Service, utilizing microwave transmission and radio telephones.

Land-Air operates a facility at Point Mugu, Calif., where data collected by the U. S. Naval Air Missile Test Center are processed. Such processing utilizes the latest electronic reading, plotting, and computing equipment.

In the field of data processing, the company maintains a division in Los Angeles offering such services on a commercial basis, involving payrolls, inventories, and other allied business functions.

In other fields the company is furnishing qualified engineering services and technical representatives to contribute in the research, development, and resolving of various problems in the fields of communication, radar, radio, and missile development.

Facilities

Most equipment research and development programs are performed at the Instrument and Electronic Division, where adequate facilities and the latest electronic test equipment are available. Production, while performed at the I. & E. Division on limited quantities, is usually performed in the Chicago Manufacturing Division. The Chicago Division also maintains an engineering Department and laboratory facilities.

Missile Background

Land-Air's experience has primarily been in the field of testing and tracking guided missiles and rockets. The greatest effort has been directed to the improvement of data collection techniques involving the development of data collection instrumentation systems.

Products—Future

Land-Air products are primarily electronic, optical, and highly specialized cameras that are offered to the various agencies of the Department of Defense, which represents a considerable future in further product development. Other products, such as the engine analyzer and associated accessories, receivers and power supplies, are offered to commercial concerns in addition to the Department of Defense. This field also represents tremendous future potentials.

Your Career

The diversification of company effort provides a multitude of opportunities in electronic, electrical, mechanical, aeronautical, and automation fields. This wide range of talent requirements is further enhanced by the youthfulness of the company, thus providing the opportunity for further development in any chosen career. The company is expanding and such expansion creates more good jobs than there are good men to fill them.

Promotions

This company's success is attributed to the policy that it purchases *performance* from its employees, rather than time. All employees are reviewed twice annually, which provides the company an opportunity to reward its employees on a merit basis.

Project Opportunity

This company believes that every key man involved in a project should be familiar with the end product.

Research

Land-Air is definitely growth minded, and fully cognizant that growth is dependent upon research.

Further Education

The company pays one half of all tuition, books, and associated educational costs upon satisfactory completion of any approved course related to an individual employee's job.

Training

A management training program as such has not been inaugurated, since current size of the company does not justify such implementation. Management training, in a more general concept, is offered in the same degree as that provisioned for further education.

Working Conditions

Individual qualifications dictate the division to which employees are assigned. Thus, assignment is made to one of the following locations: Alamogordo, Mex.; Los Angeles, Calif.; Oakland, Calif.; Cheyenne, Wyo.; Chicago, Ill.; or to Japan or Europe.

Benefits

A retirement plan has not yet been inaugurated, since Land-Air is a youthful company. Existing benefits include company-paid life insurance, hospitalization, and health and accident insurance.

Arthur D. Little, Inc.

30 Memorial Drive, Cambridge 42, Mass.

ARTHUR D. LITTLE, INC., is a consulting industrial research and engineering organization, established in 1886, and is one of the largest and most diversified of today's technical consulting companies.

Our business is to apply science, technological skill, and sound business judgment in dealing with clients' problems and aspirations.

Opportunities at ADL

Members of the technical staff feel that ADL offers opportunities to perform satisfying, productive work in a professional atmosphere. As a new staff member, you will usually begin work as one of a team assigned to a particular project. Since the typical project lasts only a few months, there is a continual flow of challenging new assignments, each having elements of novelty, variety, and interest. You will find that true job stimulation and satisfaction will result from the diversified nature of your work and from your close association with business and professional leaders. There are always opportunities for people with sound technical backgrounds who can deal effectively with clients and assume responsibility for supervising the work of others. Although most of our openings require some industrial experience, each year we add to our staff a few new graduates who show unusual promise.

The technical work at ADL, Inc., covers many fields—a few of particular interest are outlined below. Current projects include a number of assignments in fuel processing and handling, thermodynamics, upper air research, and other technical areas directly related to rocket development.

The Applied Mechanics group is primarily interested in the application of analytical methods to the solution of technical problems. Through the combination of mathematics and scientific knowledge, they solve problems by isolating and attacking the basic factors controlling a situation. Recent assignments have included work in the fields of stress analysis, dynamics, vibrations, fluid flow, heat transfer, acoustics, and noise reduction.

The Cryogenic Engineering group has a broad background in the application of the latest developments in low-temperature technology to the processing of gases. They are pioneering in the development of techniques for the handling, processing, transportation and storage of liquefied gases, such as methane, oxygen, hydrogen, and helium. Briefly, their work is a unique combination of advances on the front line of cryogenic research and the use of these developments in the design of prototype equipment. Their work demands experience and facility in the areas of gas technology, thermodynamics, refrigeration, heat transfer, and cryogenics as well as a good "down-to-earth" ability to design process equipment.

The Physics group is concerned with the application of fundamental theory to the solution of practical problems. Recent work has included studies of the fundamental properties of glass, a study of the mechanism of the explosion of ammonium nitrate, and investigations of the nature of clouds and their behavior.

Operations Research. Arthur D. Little, Inc., has been pioneering since 1949 in the application of Operations Research to industrial problems and continues its leadership in this field. Physicists, mathematicians, chemists, and engineers are developing new techniques in such diverse areas as the planning and control of production or the design and evaluation of communication and other logical systems. The scientist finds expression for his originality and analytic thinking and must draw heavily on his experience in scientific research to develop new fundamental approaches to operating problems.

Location

The Boston area, with its excellent education and research facilities, is home base for many of the nation's leading technical minds. Here are unparalleled opportunities for the pleasure and stimulus of association with fellow engineers and scientists—leaders in their fields.

Our main office is located on "Research Row" in Cambridge and our Laboratories are in West Cambridge. A few minutes' drive from the office, you are in attractive residential suburbs—pleasant New England towns—convenient to the cultural and business facilities of Boston and to the recreational attractions of New England.

Mechanical and Chemical Engineering Research Buildings

Martin

Baltimore 3, Md.

MARTIN, the pioneer in upper air research with the VIKING rockets, is the PRIME CONTRACTOR for *the first* EARTH-CIRCLING SATELLITE (VANGUARD), which will be launched during the International Geophysical Year, July 1957–December 1958. This vehicle will furnish hitherto unattainable scientific information on the upper atmosphere.

Vanguard is a three-stage rocket—the first liquid fuel rocket to be controlled without the use of fins. The three stages will lift Vanguard to approximately 300 miles in ten minutes. Careering at 18,000 miles per hour, the *satellite* will girdle the earth every 90 minutes, in an elliptical orbit. Eventually, atmospheric drag will bring it into the lower reaches of the atmosphere, where it will burn briefly and disintegrate after the manner of a meteor.

The first-stage rocket resembles the Martin Viking, which attained an altitude of 158.4 miles—a world's record for single-stage rockets.

The satellite is launched vertically. When fuel is exhausted, the first stage separates and drops off—the second stage then taking over. The second stage tilts the flight course at an angle from the vertical and, at fuel exhaustion, the number two rocket separates. Finally, the third rocket climbs to altitude, where the satellite vehicle separates and begins its orbit.

An INTERCONTINENTAL BALLISTIC MISSILE, THE TITAN, is also under way at Martin. This strategical weapon of the Air Force has a range equal to one quarter of the distance around the globe. Work on the Titan is going forward with the highest military priority. News of Martin's assignment to build this intercontinental ballistic missile was announced only this spring by the Secretary of the Air Force, so that design details on this weapon are still under strict security wraps.

Just as Vanguard extends the province of the Viking, the surface-to-surface Titan comes as a long-range successor to the Martin Matador tactical missile. Matador is the first such missile to become operational with the Air Force overseas—and the first to enter quantity production. More advanced Matador designs are in current development.

To engineers, Martin's leadership in rocket and missile design means present opportunity for an unlimited future. The Vanguard, Titan, Viking, and Matador programs are indisputable earners of that leadership. Martin has a present and continuing need for the far-sighted engineer—especially in the fields noted below.

Aerodynamics and Propulsion
Ballistics, Heat Transfer, Gas Dynamics, Propellants, Combustion, Fluid Flow

Flight Path Control
Guidance, Controls, Computers, Tracking

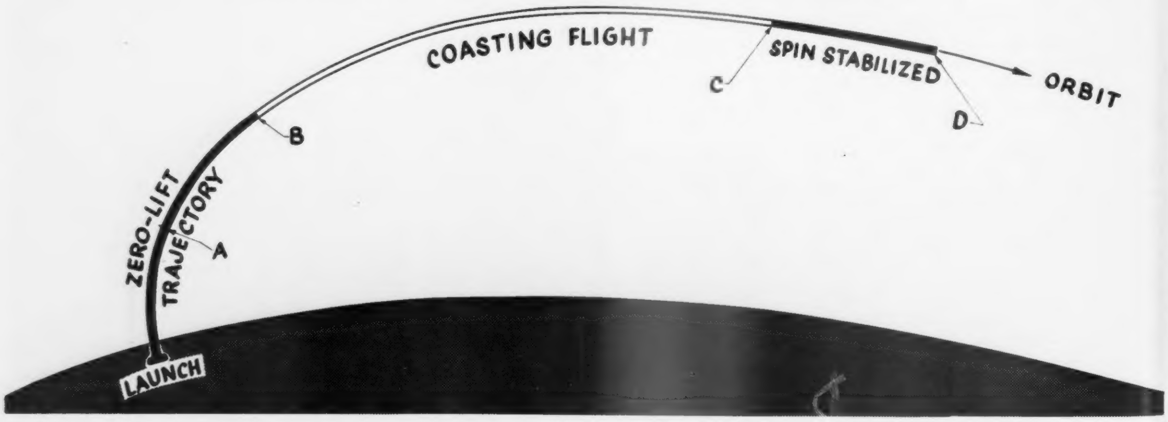
Structures
Extreme Temperature Materials, Environmental Vibration and Shock

Product Design
Airframe, Equipment Integration, Support Systems

Testing
Instrumentation, Data Processing, Telemetering, Flight Testing

Upper Atmosphere Research
Ionosphere, Meteorology, Gravity, Cosmic and Solar Radiation, Density, Pressure, Temperature

Contact: J. M. Hollyday, Martin Company, Baltimore 3, Md.



TRAJECTORY OF VANGUARD, showing burnout position of first rocket stage (A), burnout of second stage (B), initiation of third stage spin and separation of second stage (C), and burnout of third stage (D). Orbiting altitude is 300–400 miles, reached 10 minutes after launch, when the three staging rockets have been expended and the vehicle has covered 1500 miles

ARTIST'S CONCEPTION of launching of **VANGUARD** research vehicle, which will carry first man-made satellite to an orbit around earth. In background is gantry used to position the vehicle on its launching stand; also concrete blockhouse, from which scientists will fire the rocket and record its course. The Navy is sponsoring VANGUARD with support from the other two Armed Services. Launching will take place at Cocoa, Florida, during International Geophysical Year

Pan American World Airways, Inc.

Guided Missiles Range Division

Patrick Air Force Base, Florida

ENGINEERS AND TECHNICIANS are needed to operate the Air Force Missile Test Range, with its launching site near Patrick Air Force Base and its chain of bases stretching for thousands of miles into the Atlantic.

Your future may begin in Florida with Pan American World Airways, Inc., Range Contractor, and its dynamically expanding Guided Missiles Range Division. For new horizons, horizons in space, HORIZONS UNLIMITED, guide your career toward the greatest of missile test ranges.

Pan American's Guided Missiles Range Division was created in 1953 for the purpose of managing, operating, and maintaining the Air Force Missile Test Range. To direct our work here we need Project Engineers and specialists for administrative engineering, planning and design, liaison work in the fields of instrumentation—telemetry, timing, radar, and communications.

Unique opportunities are here for Electronic Engineers specializing in radar, with experience in precision tracking, search radar, and digital and analog computers. Exciting prospects are open for men with sound knowledge of radio communications, teletype, telephone, and microwave systems. Required for these positions are a BS., EE., or higher degree, *or previous experience equivalent thereto.* Chemical, civil, mechanical, and launching pad safety engineers will also be selected for key positions in one of the top-priority developments of world history. If you are a chemical engineer familiar with explosive and toxic fuels, liquid oxygen, and solid propellants—or if you have a Safety background coupled with knowledge of electronics, electromechanical systems, and missile propellants—you will be wise to contact us. Again, degrees or equivalent experience are required.

The master planning and design of intricate facilities will furnish jobs for an elite corps of civil, mechanical, and electrical engineering specialists. Prodigious plans for range facilities, modifications, and maintenance will occupy the group of civil engineers chosen. Mechanical engineers preferred are those with experience in fuels, high-pressure air systems, and the design and maintenance of pumping plants, hoisting and transport machinery. Electrical engineers with backgrounds in power distribution design and maintenance may qualify for jobs of unusually challenging interest.

If you need short-range inducements and special offers to join our team of engineering specialists, you will not find them. We want men who think long-range, to operate the longest missile test range in the world. Advancement opportunities *are* especially good, due to our policy of promotion from within. A man's advancement depends only on his ability. Starting salaries compare favorably with others in the field. Merit increases and prompt promotions are available to men who qualify. We are proud of our Company benefit program, which is one of the best in the country. It includes group insurances, retirement, sick leave, paid vacations, recreation, and up to 85 per cent discounts for employees and dependents on world-wide and domestic air travel. As for pleasant living, Florida's virtual monopoly on golden days and starlit nights is still unchallenged!

A few select students graduating with degrees in the fields listed will be accepted without experience and will find Pan American a uniquely suitable place to begin their careers. Operating under senior engineers will provide background and training unobtainable elsewhere.

Key supervisors are young men with initiative, imagination, and a great deal of creative ability. They weighed the difference between a job and a *future*, and chose Pan American—as you may wish to do. If you would like to become a part of this future, to share in vast progress which may go beyond the realms of this earth, fix your sights on the stars and *Guide Your Career Toward Guided Missiles!*

Experience résumés should be submitted to the Industrial Relations Manager, Pan American World Airways, Inc., Guided Missiles Range Division, OMU Box 308, Patrick Air Force Base, Fla. All résumés will be acknowledged and interviews will be promptly arranged with those believed qualified to join the Pan American team.

The AFMTC missile test range extends 5000 miles

PAA technicians supervise missile control systems

The Ramo-Wooldridge Corporation

5730 Arbor Vitae Street, Los Angeles 45, Calif.

THE Ramo-Wooldridge Corporation was founded in September 1953, to conduct research, development, and manufacturing operations in the broad fields of electronic systems and guided missiles. From the beginning, the principal company objective was to establish and maintain a high level of competence in major systems development and engineering.

Both because of the national need and the inclination and experience of the key people, the emphasis in The Ramo-Wooldridge Corporation is on the development of products containing a high content of scientific and engineering newness. Prominent examples are the Intercontinental Ballistic Missile and the Intermediate Range Ballistic Missile, Air Force programs for which we have over-all systems engineering responsibility. Other examples are communications, fire control, and computer programs for the military, and automation and operations research projects for business and industry.

All features of the organization and of the operational procedures of the company are designed to be as appropriate as possible to the special needs of the professional scientist and engineer. Because of the high degree of scientific and engineering effort that is required for the successful development of major systems, it is important that a company organized for this purpose should assign to technically trained people more dominant roles in the management and control of the business than is customary or necessary in most industrial organizations. In The Ramo-Wooldridge Corporation, scientific activities are always headed by scientists who, when required, are provided with the administrative and business-type assistants needed to carry out their organizational responsibilities.

The following paragraphs constitute a brief progress report on the current status of our growth and on the activities in which we are engaged.

Technical Personnel

Our total employment is 1750, but such figures tell only a limited story. Personnel quality factors are most important in our kind of business. We believe we are doing well in this respect. Of the 110 PhD.'s, 145 MS.'s, and 205 BS.'s or BA.'s who today make up our professional scientific and engineering staff, a gratifyingly high percentage are men of broad experience and, occasionally, national reputation in their fields.

Financing

Adequate financing for our growth, as well as other important corporate advantages, were secured early by establishing strong ties with Thompson Products, Inc., one of the nation's most progressive large corporations. Arrangements have been made with Thompson for up to $20,000,000 of additional financing to cover the Ramo-Wooldridge expansion requirements of the next few years.

Facilities

Our Los Angeles facilities, located in the International Airport area, consist of eight buildings totaling 360,000 square feet of modern research and development space. By the end of 1956, an additional 220,000 square feet of offices and laboratories will be completed or nearing completion to bring the total to 580,000 square feet, including the first two buildings of our new 40-acre Research and Development Center.

Manufacturing

We are somewhat ahead of the usual systems development schedule, with some of our projects having arrived at the field and flight-test stages. Arrangements are currently being completed to provide a manufacturing plant for quantity production of electronic systems. Construction of the initial unit of 172,000 square feet is expected to start in May or June of this year, located on a 640-acre site which has been purchased in suburban Denver, Colo.

Fields of Activity

The technical areas available to a company specializing in advanced electronic systems and guided missiles work are numerous, and no attempt has been made to impose narrow limits on the areas considered suitable for future planning. Therefore the following list of fields simply outlines the kind of work that is currently under way, and that is expected to continue and expand during the next several years:

Guided Missile Research and Development
Aerodynamics and Propulsion Systems
Communications Systems
Automation and Data Processing
Digital Computers and Control Systems
Airborne Electronic and Control Systems
Electronic Instrumentation and Test Equipment
Basic Electronic and Aeronautical Research

For a copy of our booklet, "An Introduction to The Ramo-Wooldridge Corporation," or other additional information, write to:

MR. D. L. PYKE
The Ramo-Wooldridge Corporation
5730 Arbor Vitae Street
Los Angeles 45, Calif.

Reaction Motors, Inc.

Ford Road, Denville, N. J.

TO the forward thinking engineer or scientist who is capable of putting advanced thinking into practice, Reaction Motors—founders of the rocket industry in America—offers highly rewarding opportunities for the application of your engineering skill working with other scientists and engineers in the rocket field.

RMI—A Pioneer in Rockets and Missiles

Reaction Motors, incorporated in 1941, has paced the growth of the rocket industry. Today, in its newly expanded plant and facilities, RMI's growth is continuing at a faster rate than ever. Its products have pioneered the field of applications for rocket power and set records which are still to be equaled. RMI engines have been used in the Skyrocket, X-1 and X-1A supersonic airplanes, the Lark guided missile, and the Viking Missile which set major speed and altitude records. With these accomplishments as a background, RMI is developing new engines for the future, which we believe will surpass all previous records.

Current Expansion

Working with top scientists and engineers you will have an opportunity to develop creativeness and enthusiasm and to work on high level assignments from original research to final test and production. A new multi-million dollar plant has just been occupied and the next step in RMI's expansion is already beyond the planning stages. A 60 per cent increase in business during the past year is indicative of the vitality and stability of RMI's place in the rocket industry. Employment is at an all-time high. RMI has openings at all levels for technical personnel—opportunities that lead to positions of responsibility, with your own ability the only limitation. For employee security and job satisfaction, RMI has an excellent fringe benefit program including paid vacations, retirement program, medical and surgical hospitalization, accident insurance plans, tuition assistance plans, and other benefits second to none in the industry.

Immediate Openings

Positions are available for graduate engineers with experience or training in the following fields:

Nuclear energy for rocket devices
Stress analysis—aircraft engines or airframes
Environmental testing of components
Aircraft power plant installations
General project engineering work
Engine controls and control systems
Internal combustion for jet or rocket engine applications
Preliminary design or proposal experience in aircraft power plant field
Formulation of control system problems
Computer setup and solution analysis
Design of airframe or aircraft engine type parts
Servomechanisms
Design and development of hydraulic, pneumatic, and mechanical components and systems synthesis
Thrust chamber and injector design and combustion stability
Rotating machinery design and consultation
Analysis and consultation on rocket engines and power plant systems
Rocket engine testing and instrumentation

Location

Surrounded by many excellent suburban communities, RMI is located in the beautiful lake region of Northern New Jersey, only 35 miles from New York City. Swimming, golfing, and fishing are popular sports in this year-round vacation land. Nearby communities boast excellent religious, cultural, and educational activities. Ample housing is available and easy access is provided by major highways.

Your future with RMI is as exciting as the rocket industry itself. Now is the time to associate yourself with this rapidly expanding industry. Write today enclosing a résumé of your education, experience, and salary requirements to the Employment Manager.

Navy "Viking" high-altitude research rocket powered by an RMI 20,000 lb thrust engine leaves launching platform

Reaction Motor's newly expanded test stand facilities, where rocket engines are hot tested for thrust, chamber pressure, temperature, stresses, etc., and later released for field installation in aircraft or missiles

Republic Aviation Corporation

Guided Missiles Division

Hicksville, Long Island, N. Y.

A Young Division

of a long established company. This is the kind of "in-at-the-beginning" opportunity that offers a young engineer or scientist an unusual opportunity to make a name for himself, far sooner than he could normally hope to do.

You Work With Leaders

Working with men who are recognized specialists in all phases of both pilotless and piloted flight, you can learn and grow professionally at a rapid rate—and scheduled expansion at Republic's Guided Missiles Division provides frequent promotions, where ability is shown.

Location: Hicksville

The Division is small enough to permit close cooperation of project and research teams, yet large enough to include all facilities for a top level industrial enterprise. The Division operates its own new plant at Hicksville, Long Island, 30 miles from New York, and separate from the main Republic Farmingdale plant.

Significant contributions to the evolution of weapon systems concepts at the research, development and experimental levels are being made at Republic today, from missile feasibility studies and guidance development to aerodynamic analysis and missile system instrumentation, with special emphasis in these vital areas:

- Missile Reconnaissance
- Guidance and Control Problems
- Upper Atmosphere Research
- Special Weapons
- High Mach Number Problems

Air-to-Air Missiles

Right now, new research and project teams are being organized to develop advanced air-to-air missiles. Consequently there are a number of openings for recent graduates in the fields listed at the right.

Research Facilities

The modern research facilities behind Republic men are of a caliber to inspire their best creative efforts, and new equipment is continually being acquired, to the tune of $12,000,000 in 1956.

Promotion Policy

Our promotion policy is to advance from within to supervisory and specialist positions; to aid the young men who join us to fit themselves for promotion through technical courses and seminars; and to give assignments of a type to demonstrate their professional skill and creative ability.

Education Assistance

Engineers and scientists at Republic are encouraged to take graduate work leading to advanced degrees at famous institutions in the New York metropolitan area. Colleges and universities such as Columbia University, New York University, Brooklyn Polytechnic Institute, Fordham University, Hofstra, Adelphi, and others are located in the Greater New York area within easy reach of the Hicksville plant. And Republic pays $^{2}/_{3}$ of tuition and fees.

Retirement Income Plan

Republic's 2-Fold Retirement Income Plan is the talk of the industry. Part I provides a basic retirement income paid in full by the company. Part II is optional. It offers additional retirement income on a liberal contributory basis, Republic paying over 50 per cent. No nagging worries about the future plague Republic's permanent staff.

Here's How It Works

Take the case of a hypothetical engineer who joined Republic on January 1, 1956, and averages $8000 a year for 15 years; then retires aged 65. If he elected Part II of the Plan, he will have a total monthly retirement income of $225.80 including his social security. For this, he himself will have contributed only $8.40 a month to the Republic Retirement Income Plan. Of course, the more you earn, the higher your Retirement Income will be.

Other Benefits

Republic's benefits program includes many other outstanding provisions, such as an all-expense paid relocation plan for qualified engineers living outside the New York City-Long Island area. Also company-paid life, accident, and health insurance and hospital-surgical benefits for the whole family.

Long Island Living

Your personal life is set in pleasant places when you work for Republic. You live on Long Island, with its fabulous beaches and state parks. Fishing, swimming, boating are right at your doorstep. You can play golf, tennis, even polo. Yet all the entertainment and cultural facilities of downtown New York are close at hand.

Attractive homes are available in modern suburban areas; shopping centers; schools; and many opportunities for community activities and social life.

Current Opportunities

with high potential for your career development exist at Republic's Guided Missiles Division today in:

- Weapons Systems Analysis
- Control Systems
- Servo
- Propulsion
- Operations Research

High Salaries Paid

In fact, Republic is rated a top-paying employer in the field—and these are permanent positions—creative, rewarding employment in the missile sciences, involving a wide range of problems vital to the defense of the United States. You owe it to your future to look into the opportunities at Republic.

Please send details of your technical background to the Administrative Engineer: Mr. R. R. Reissig.

A convenient interview will be arranged at the Guided Missiles Division of Republic Aviation Corporation, in Hicksville, Long Island, N. Y.

Rocketdyne

A Division of North American Aviation, Inc.

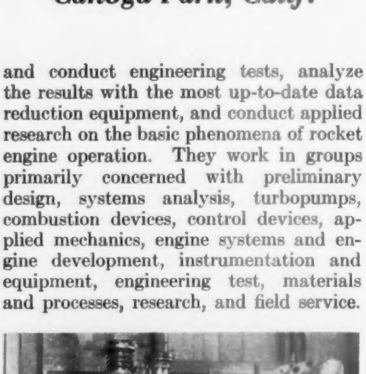
Canoga Park, Calif.

IN 1945, long-range guided missile development was initiated by North American Aviation. A group of missile and rocket engine experts formed the nucleus of an effort so broad in scope that it is now a new industry. An important part of this effort is rocket engine development. In 1951, North American's Propulsion Development Group employed 500 personnel. By 1954, the number had risen to nearly 2000. It will be 8000 by the end of 1956. Because of the growing importance of liquid-propellant rocket engines and the dramatic progress achieved by the Propulsion Center, it was recently given divisional status by North American, and named Rocketdyne. Its main offices are located in Canoga Park, a growing community in the San Fernando Valley near Los Angeles.

While the work is directed by men who have been in the industry for years, much of it is done by young engineers and scientists who obtained their degrees only a short time ago. At Rocketdyne they receive intensive, specialized training: then go to work under the guidance of the nation's top rocket experts.

Engineers at Rocketdyne are pioneers. They deal with physical phenomena of magnitudes difficult to comprehend: speeds and forces, temperatures and stresses virtually unknown in general industry. They pump fuels and oxidizers at almost unbelievable flow rates. They generate, in a package smaller than the family automobile, more power than the total output of Hoover Dam. They explore fluid dynamics, supersonic aerodynamics, thermodynamics, hydraulics, pneumatics, chemistry, electronics—virtually all the fields of modern engineering. In their experimental investigations they use thousands of instruments, huge pumps, mazes of ducts, valves, and tanks, to handle and control the flow of fluids known only in the laboratory test tube a few years back. On giant test stands, capable of withstanding up to one million pounds of thrust, they create a thunder symbolic of a concept as exciting as any that man has yet generated. Their work is fascinating—and important. To the engineer or scientist seeking extraordinary career opportunities, probably no other field offers as many challenges—or is as rewarding.

Rocket Engineering presents opportunities in many fields of specialization. Engineers with degrees in aeronautical, chemical, civil, electrical, electronic, general, metallurgical, and mechanical engineering, and scientists specializing in physics, chemistry, and mathematics, are vitally needed in the industry today. At Rocketdyne they perfect control devices, analyze and design engine systems, create and install precision instrumentation, set up and conduct engineering tests, analyze the results with the most up-to-date data reduction equipment, and conduct applied research on the basic phenomena of rocket engine operation. They work in groups primarily concerned with preliminary design, systems analysis, turbopumps, combustion devices, control devices, applied mechanics, engine systems and engine development, instrumentation and equipment, engineering test, materials and processes, research, and field service.



This 50,000-lb thrust engine will be employed on an Air Force test sled, following calibration and thorough qualification testing. Small Rocketdyne engines such as this one can accelerate from a dead stop to 1500 mph in 4.5 sec

Preliminary Design engineers conceive, analyze, and evaluate new and advanced concepts for rockets and related devices, and work to improve the performance, versatility, and usefulness of existing engine models. An important part of this work is the preparation of long-range plans and programs. Preliminary design engineers try to outguess the future by extending the state of the art to tomorrow's needs in engine performance. They conduct technical liaison with government agencies and leading missile engineering companies to establish engine configurations for all types of applications. They prepare the technical proposals for these new engines in the form of reports, drawings, charts, and other media. Preliminary design offers the opportunity to obtain a broad outlook in the complete field of rocket propulsion. Because of its many facets, the field requires a clear, over-all understanding of the many technologies called into play in rocket development.

Systems Analysis is the gateway to design and development. It is concerned with the theoretical analysis of the complete engine system as it relates to the operation of the four major categories of components: turbopumps, combustion devices, control devices, and interconnect components. It involves the prediction of engine performance during missile flight which requires the simultaneous simulation of such hydrodynamic, thermodynamic, and mechanical elements as ducts, nozzles, valves, high-speed pumps, turbines, and controls. The *systems engineering* concept is employed, which permits the analysis of the engine as an operating unit, including the interaction between the major components and controls of a complex system. For maximum performance and efficiency, the engine must function as a well-balanced, integrated unit. The latest tools of analysis, including high-speed analog and digital computers, are used to achieve this goal and to extend the earthbound engineer's ability to predict and cope with problems arising from engine operation at extreme altitudes.

The turbopump is the heart of the rocket engine, pumping tremendous quantities of fuel and oxidizer into the thrust chamber. Pound for pound, a turbopump is probably the most powerful pumping machine yet developed by engineering skill. Its design is extremely critical: low weight, high efficiency, and extreme reliability are of utmost importance. Each component must conform to severe weight limitations, yet must meet exacting performance specifications under extreme environmental conditions far exceeding those of commercial industries. Design and development engineering of turbopumps extends the boundaries of technology and presents challenging opportunities in the fields of thermodynamics, fluid mechanics, and machine design. Turbopump development at Rocketdyne entails analysis, design, and development of high-pressure-ratio supersonic turbines, high-speed gear boxes, radial and axial flow pumps, rotating liquid and gas seals, and other mechanical components. Requirements also exist for applied research to extend the knowledge of cavitation, fluid flow in impellers, and the aerodynamics of supersonic flow in turbines.

Combustion Devices engineers at Rocketdyne are responsible for the design and development of thrust chambers, injectors, and gas generators. Perfection of more efficient combustion devices, with the resulting increase in range, payload, reliability, and flexibility, is a challenging goal for engineers with background in thermodynamics, hydrodynamics, and aerodynamics, and an appreciation of modern machine design practices, metallurgy, and stress analysis. Higher flow rates and chamber pressures create further problems in the field of heat transfer. These require analysis of heat transfer through the walls of regeneratively cooled

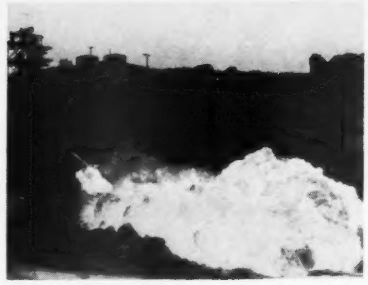
thrust chambers, and through the face of injectors. This work explores the mysteries of the boundary layer on the gas side of the chamber wall, and the non-uniform distribution on the coolant side where extreme rates of heat transfer present unique problems.

The attainment of stable ignition under a variety of environmental conditions is another subject of intensive study. Propellants entering the thrust chamber at extremely high flow rates must ignite instantaneously and smoothly in order to prevent rough combustion, an aborted test, perhaps a damaged engine. Analysis of the ignition phase and ignition devices, and of propellant flow, is involved in the solution of these problems. Scientists at Rocketdyne are seeking a complete understanding of the basic phenomena of combustion, which encompasses a precise expression of fluid flow, combustion mechanics, droplet formation, ignition characteristics, and flame propagation.

The control functions of a rocket engine demand precise operation of numerous pneumatic and electrical components, proper sequencing at very high speeds, high sensitivity, and ruggedness and extreme reliability, which are all vital. Specialists in electronics, electrical, mechanical, and servo engineering find these problems stimulating and rewarding. Servo engineers encounter unusual problems in the control of mixture ratio, thrust and other parameters arising from complex transients. Experience with fuel systems of ramjet, turbojet, and reciprocating engines, electronic or hydromechanical flight control, and complex process instrumentation is applicable in this work.

Working closely with the Preliminary Design and the Development engineers, the Applied Mechanics Group subjects the rocket engine, assemblies, and components to searching study. The demand for lightweight design, combined with absolute structural reliability, necessitates highly analytical approaches combined with rigorous proof tests. High rotational speed of turbines and pumps, and extremes of temperature within the same piece of equipment, lead to involved problems in both stress and vibration. The unusual dynamic response of both rocket engines and components make the analysis of complex linear and nonlinear systems particularly interesting. To the analytically minded engineer, the study of transfer functions in systems and components, and of vibration and surge problems in rotating and static assemblies, offers a continuing challenge.

The general arrangement of the engine configuration to conform to the space limitations of the final missile is determined by the Engine Systems Group and requires unusual talent for descriptive geometry. Some places are too hot, others too cold. Often, both conditions are present within the same component, usually at high stress levels. New engine types are constantly in design, and others are undergoing modification, keeping the Engine Systems engineers continually occupied with an array of design and development problems. They are responsible for the structural framing which unites the engine as a mechanical assembly, and for a host of interconnecting components—flexible feed lines, expansion joints, thrust mounts, heat exchangers. They also direct the construction of full-scale mockups, design the laboratory test setups for evaluation of components, and direct the fabrication of experimental engines.



A liquid propellant rocket engine which will power intercontinental missiles. This engine is used in horizontal test firing

At the focal point of the intense activity associated with engine testing and development are engineers of the Engine Development Group. They specify the conditions under which the rocket engine will be tested—start sequence, regulation, duration, cutoff, and instrumentation. They evaluate the data obtained, aided by the most advanced processing and computing equipment available. In Engine Development, versatile talents and broad interests are required to direct the extensive programs involved. Training in Engine Development is highly profitable in terms of professional growth. The work provides an opportunity for a thorough understanding of rocket engine technology, from design, development, testing, and beyond—to acceptance, flight approval, qualification, reliability, and performance in the aircraft.

The massive test stands, mazes of pressure lines and cables, and complex systems of pickups and recorders employed in engine testing are the responsibility of Instrumentation and Equipment engineers, who must design and develop elaborate test structures, propellant feed systems, utility services, and test fixtures. Rocketdyne's Propulsion Field Laboratory is second to none in facilities for testing rocket engines and components. To cope with the rapid advances in rocket technology, Instrumentation and Equipment engineers develop special computers and instrumentation to insure reliable, accurate, automatic, and rapid recording of test data. Every parameter of engine operation must be measured. The high degree of accuracy required in rocketry stimulates rapid progress in the techniques of measurement.

Components Testing is a particularly important phase of Engineering Test at Rocketdyne, in which scores of subsystems, control servomechanisms and parts must be proof-tested to verify predicted performances. Following successful component testing, the large rocket engines are assembled and installed in static test stands capable of restraining up to one million pounds of thrust. The propellant tanks are loaded, and the area is evacuated. In the control center, the count-down simulates missile flight procedures, and as the test area reverberates with the thunder of tremendous forces at work, automatic recorders amass data on pressures, flows, temperature, and thrust.

The engineering activities described above demand an immense volume of technical facts—new facts—to make headway in the unexplored reaches of rocket engineering. Rocketdyne Research attempts to supply these facts: facts about heat transfer where the thermal parameeters are pushed to the extreme and beyond; facts about combustion kinetics where physical states, temperatures, pressures, and reactions are so intermingled as to constitute a new field of combustion; facts about measurement devices and techniques for conditions in which 5000 F is cool, a millisecond is a long time, where the conventional concept of a fast transient is classed as steady state; facts about chemical propellants, about flames, about ignition, about superpressure. The list is long, the need immediate. Rocketdyne research engineers bring these facts to light, shake them down, and relay them to design and development engineers, who convert them to a better, lower-cost product. The well-educated researcher in any of the physical sciences, with the "research attitude" and a hearty appreciation for the engineer, the designer, the product, and the cost sheet, will find Rocketdyne an unusually stimulating and rewarding place to work.

To develop the specific skills and abilities demanded by a rapidly advancing technology, Rocketdyne provides specialized training to suit the employee for the best performance of his particular job, and to familiarize him with his general responsibilities. Instructors present specially prepared technical training courses covering all phases of Rocketdyne activity. Functional programs of leadership guidance aid the employee to take the supervisory responsibility required by Rocketdyne's rapid growth. An educational refund plan encourages the continuation of education outside the plant, where employees may attend any of several of Southern California's finest colleges and universities. Within a short driving distance from Canoga Park are California Institue of Technology, University of California at Los Angeles, and University of Southern California.

In addition to the educational refund plan, company benefits include an insurance plan, retirement plan, suggestion system and patent award plan, periodic review for promotion, a salary increase, and paid vacations and holidays. Opportunities for recreation in the general area are unlimited, for Rocketdyne is in the center of an all-season play area. Camping, hunting, and fishing are popular sports in the surrounding mountains. The clean, uncrowded beaches of Malibu and Zuma are 30 minutes away. In the nearby San Gabriel Mountains, skiing is the favorite winter sport. In the San Fernando Valley, the climate is mild, and the skies are clear about 350 days per year. Excellent valley apartments and homes are available a short distance from Rocketdyne. Schools, churches, retail stores, and service shops of all types are also available, as the result of a continuing expansion in this suburban area.

Rohm & Haas Company

Redstone Arsenal Research Division

Huntsville, Ala.

Organization

THE Redstone Arsenal Research Division of Rohm & Haas Company is a nonprofit division of this major chemical manufacturer, operated for the Army Ordnance Corps as a national service with the aim of making major advances in the field of solid propellant rocket science. A highly competent technical staff of approximately sixty scientists and engineers forms the nucleus of the organization. Supporting this group are a number of able laboratory and technical assistants, draftsmen, clerical, and secretarial employees. This support releases the full potential of the technical man by relieving him of routine or nontechnical work. The full strength of the Division is roughly two hundred and fifty.

The research program is fundamental, integrated, and flexible in approach. The major effort of the Division is constantly directed toward those phases of solid propellant rocket science which offer the greatest promise of major achievement. Approximately one half of the Division's effort is in basic research and long-range development programs, the rest being divided between immediate and near-term applications.

Aims

Broadly, the organization's goals can be classified under four headings:

Propellant Chemistry

Development of improved propellants and investigation of factors influencing propellant effectiveness.

Propellant Development

Design and development of practical and reliable processes for the semiworks scale manufacture of promising compositions.

Interior Ballistics

Development of superior propulsion units and investigation of the effect of various factors on rocket motor performance.

Weapons Research

Development and optimization of improved weapons systems including design of metal components.

Scientific Opportunities

Many scientific disciplines are represented on the Division's technical staff. The outline below indicates these fields of training and some of the programs in which these talents are utilized:

Organic Chemistry

Basic chemistry of organic compounds with explosive potential; development of new synthetic methods and synthesis of new explosive compounds; interpretation of synthetic reaction processes through instrumental methods.

Organic Chemistry
Physical Chemistry
Polymer Chemistry

Fundamental studies in propellant chemistry; correlation of molecular structure with ballistic characteristics; laboratory scale compounding and evaluation of new propellant compositions; applications of polymer chemistry to solid rocket propellants.

Analytical Chemistry

Development of analytical methods for novel functional groups; analysis of propellant compositions and reaction products.

Physical Chemistry

Fundamental kinetic studies of reactions encountered in propellant ignition and combustion; thermal decomposition studies of novel compounds; basic investigations of influence of heat transfer, fluid flow, etc., on propellant burning in rocket motors.

Chemical Engineering

Development of processes for promising new propellant compositions and their ingredients; design and economic evaluation of chemical processes.

Applied Mathematics
Engineering Physics
Mechanical Engineering
Physics

Basic studies of interior and exterior ballistic phenomena—influence of heat transfer, fluid flow, aerodynamic factors, malalignments, etc., on weapon system performance; preliminary design and evaluation of propellant charges; development and optimization of new propulsion units and weapon systems. Design and development of novel experimental devices; measurement of physical properties of propellants and correlation of these properties with ballistic performance.

Mechanical Engineering

Design of metal components for weapons; service design work on gadgets, dies, fixtures, and tools.

Electronics Engineering

Design, development, and maintenance of unique electronic instruments.

Location

The facilities of the Redstone Arsenal Research Division are government owned and are located at Redstone Arsenal in Huntsville, Ala. Redstone Arsenal is that portion of the Army Ordnance establishment ultimately responsible for all research, design, development and procurement of rockets and guided missiles.

The city of Huntsville, with a population of roughly 50,000, is situated in attractive country in northern Alabama. Various outdoor and cultural activities are available nearby.

Benefits and Pay

The Redstone Arsenal Research Division is an integral part of Rohm & Haas Company and employees enjoy the same opportunities for advancement and job security as those at other company locations. Pay practices and company benefits are consistent with those at other company locations and are competitive with the chemical industry.

To those interested in rocket technology, Redstone Arsenal Research Division of Rohm & Haas Company offers the opportunity for basic and applied research in a field of vital interest. Apply by letter, giving qualifications, to Personnel Department, Rohm & Haas Company, Redstone Arsenal Research Division, Huntsville, Ala.

Thompson Products, Inc.

Accessories Division

23555 Euclid Avenue, Cleveland 17, Ohio

What We Make

THE Accessories Division of Thompson Products, Inc., sponsor of the Thompson Trophy Race, is devoted exclusively to the development and manufacture of rocket and aircraft accessory equipment.

The Division does a complete development and production job. It takes the inception of ideas through design, drafting, model manufacture, development testing, manufacturing, and service. The Accessories Division manufactures auxiliary power units, turbine-driven rocket propellant pumps, air turbine-driven fuel pumps, aircraft booster pumps, high-pressure fuel pumps, speed and flow control units, and hot air turbine power drives.

Our Facilities and Abilities

Tomorrow's rocket and aircraft accessories are developed in a $12 million development laboratory located at the Tapco plant, Cleveland. This facility includes an available high-pressure, high-temperature air supply of 2100 pounds per minute. The total laboratory floor space is 60,000 square feet; about half the space is devoted to test and half to supporting equipment. In addition to the air supply there is an extensive fuel storage area, walk-in environmental chambers, an assortment of dynamometers up to 500 hp, a high-capacity altitude exhaust system, and an instrument department to meet all development measuring needs.

The Division History

The Division was founded in 1941 when the parent company, numbering 10,391 employees, put into effect its plan of forming divisions to increase operating efficiency. Starting with aircraft vane pumps and booster pumps, the proprietary products became an increasingly important part of the Division's growth. The Division pioneered the tank-mounted booster pump and is today the leading manufacturer. In 1950, air turbine pumps, air drives, and high-pressure fuel pumps were added. In 1955, the Division undertook the development of auxiliary power units.

Today, the total company employment has reached 21,218. The Division has grown to 2200 persons with research facilities at Cleveland, Ohio; Inglewood, Calif.; and Portland, Ore. Service facilities are located at Cleveland, Ohio; Hartford, Conn.; Inglewood, Calif.; and Seattle, Wash.

Security

This steady growth company provides a funded retirement plan which, with social security, can amount to 40 per cent of your five highest earning years. Hospital, surgical, and low-cost group life insurance is sponsored by the company and is available to all employees. The company's wage structure is keyed to the Department of Labor's cost-of-living index so that "cost of living" payments proportional to this index are made in addition to the regular salary. Also, there are systematic salary review periods to assure that all technical employees are reimbursed commensurate with their performance and growth.

Labor-Management relations have been so successful that, since the founding of the company in 1901, there has never been a strike or interruption of operations because of a labor problem.

Recreational and Cultural Advantages

Located in Cleveland, the plant is within easy driving distance of one of Ohio's most beautiful residential areas. Cleveland is a richly endowed cultural center and has every recreational facility. The Cleveland Symphony Orchestra and Museum of Art are internationally famous. In addition, the company sponsors its own recreational program embracing hunting, fishing, chess, bowling, golfing, baseball, orchestra, and choir activities.

The Division is located within a few miles of Case Institute of Technology and Western Reserve University where graduate courses, leading to masters and doctors degrees, can be taken. The company actively supports both undergraduate and graduate scholarships. Also, the company and the universities have established programs whereby technical employees are given every assistance in furthering their education.

A Career for You?

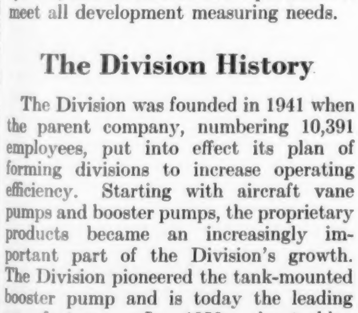
The future is bright at Thompson. A number of power unit development programs are now in progress. An aggressive development engineering department has developed new products fast enough to result in a rapidly expanding business.

The Division offers development engineering opportunities in all fields of mechanical engineering, including:

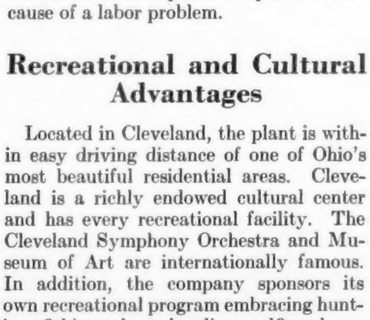
(1) Mechanical design
(2) Applied mechanics
(3) Fluid mechanics
(4) Combustion
(5) Servomechanisms
(6) Stress analysis
(7) Test engineers

The engineer has the opportunity to follow a project all the way from the idea phase to production. This broad base of experience is such that the development engineer can progress into a specialized engineering field, project supervision, production engineering or engineering sales, etc. For those who are interested in management and show promise in this area, the company conducts a management training course which extends for a period of a year for each group of trainees.

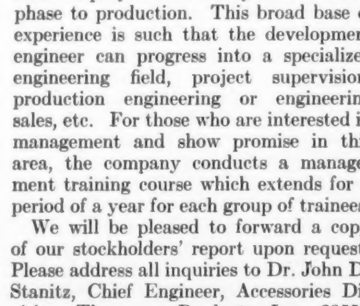
We will be pleased to forward a copy of our stockholders' report upon request. Please address all inquiries to Dr. John D. Stanitz, Chief Engineer, Accessories Division, Thompson Products, Inc., 23555 Euclid Avenue, Cleveland 17, Ohio.



Aerial view of the development laboratory



Air turbine-driven centrifugal fuel pump and controls



Altitude test installation of air turbine drive

Thiokol Chemical Corporation

Rocket Divisions

Home Office: Trenton, New Jersey

Introduction

THIOKOL Chemical Corporation, a dynamic and rapidly expanding organization, is playing an outstanding part in the important field of rocket and guided missile propulsion. In late 1955 and early this year two significant developments in rocketry were announced: Thiokol Chemical Corporation had developed a solid propellant motor for the important air-to-air Falcon missile produced by Hughes Aircraft Company. The second announcement stated that the Hermes R-V-A-10 rocket developed jointly by Thiokol Chemical Corporation and General Electic Company had been successfully flight tested. The R-V-A-10 utilized the largest solid propellant motor announced to date. The significance of these developments lies in the publicly demonstrated versatility of Thiokol rocket motors as having virtually no limit to the size to which they can be produced and yet can be made small and light enough to be practical for use in air-to-air guided missile systems. The leadership that Thiokol has established in the field of solid propellant propulsion systems can be traced back thirty years to an accidental reaction discovered by a Kansas City chemist in an attempt to produce an economical and efficient antifreeze for automobile use.

The new Army Ordnance solid propellant rocket, the RV-A-10, starts moving slowly up along its launcher, then with a burst of power zooms into space. Jointly developed by Ordnance, General Electric, and Thiokol Chemical Corporation, the RV-A-10 establishes the feasibility of solid propellant units for large, long-range, and high altitude missiles

Rubber to Rockets

When Dr. J. C. Patrick mixed ethylene dichloride and sodium polysulfide together in his experiments the results were not the much hoped-for perfect antifreeze but rather a substance that looked, felt, and acted like natural rubber. This discovery led to the first synthetic rubber produced commercially. Named Thiokol (from the Greek *thios* meaning sulphur and the Arabic *kolas* meaning gum), the synthetic rubber products through the years have gained continually greater commercial importance. They do not swell, deteriorate, or otherwise alter their physical characteristics in the presence of gasoline, air, and many chemicals which attack and break down natural rubber. A variety of applications including materials for gaskets, caulking compounds, sealants, adhesives, special putties, and plasticizers are made from Thiokol products.

Shortly after World War II, Jet Propulsion Laboratory of the California Institute of Technology found that Thiokol synthetic rubbers mixed with other chemicals could be used as fuels for rockets. So effective have been the subsequent developments from this initial finding that Thiokol Chemical Corporation is now recognized as a foremost leader in the field of advanced solid propellant propulsion systems.

Powered by a Thiokol Chemical Corporation motor, the Hughes Falcon has been publicized as one of the most effective air-to-air guided missiles currently produced. The Hughes Falcon offers an excellent demonstration of the application of Thiokol rocket motors to guided missile systems

Scope

Thiokol's rocket divisions are engaged in a wide range of activities including basic and applied research and continuing through manufacturing and final testing of many types and sizes of solid propellant propulsion systems. Professional personnel from many fields have been brought together in a uniquely close-knit well coordinated association directed toward increasingly greater achievements. The skills, imagination, and individual as well as collective enthusiasm of this group have been responsible for the company's present growth in the field of rocketry.

Development of successful power plants stems largely from Thiokol's "systems" concept of rocket motor development. Under this concept of rocket motor design, all of the requirements of the missile are taken into consideration before the propulsion unit is put on the drawing-boards. The motor's thrust, duration, size, and shape are all governed by the specific application for which the unit is intended.

Close coordination is conducted with the missile prime contractor to consider problems such as aerodynamic stability, center of gravity requirements, guidance system impact and vibration resistance, wing and fin attachments, and other overall missile problems.

With the full realization that relatively few individuals have gained experience in rocketry, Thiokol has instituted programs whereby engineers and other scientific personnel are encouraged to adapt their experience and training to the new and rapidly expanding rocket industry. The extremely low turnover of the company's employees can be attributed in part to several factors.

Permeating the entire Thiokol organization is the concept that the company is only as good as its employees. Individuality and initiative are encouraged; talent and achievement are recognized. The team spirit of the organization inspires both confidence and enthusiasm.

Locations

Almost 2000 people are currently employed by Thiokol's three rocket divisions. This figure is expected to materially increase as new facilities and programs are put into operation.

At its Redstone Division, Thiokol Chemical Corporation operates the largest contractor facility located on the very important Redstone Arsenal near Huntsville, Ala. Over nine hundred employees are engaged in developing the most effective solid propellant propulsion systems known. Redstone Division scientists and engineers have established that solid propellants can compete successfully with, and in fact have many advantages over, more publicized liquid propellant motors. The continuing growth of programs in propulsion system development at the Redstone Division has created openings for technically trained individuals interested in work which constantly challenges imagination and offers maximum incentive for personal achievement.

Company-owned facilities for research and development of rocket projects are operated at Elkton, Md. Many material contributions to modern rocketry are made by Elkton's competent staff. Increasing demands on the Elkton Division resulting from successful achievements have provided a number of opportunities for engineers who are interested in working on advanced types of propulsions systems.

Manufacturing of Thiokol rocket motors is now under way at what may be the country's largest and newest facility designed exclusively for the production of solid propellant rocket motors. Located near Marshall, Tex., at the Longhorn Ordance Works, members of Thiokol's rocket groups have designed, planned, and directed the construction of this unique plant. A master Industrial Engineering Plan has been inaugurated at Longhorn to develop the most modern types of production equipment, techniques, and processes. Production, Quality Control, Planning, and other plant activities are under constant study to improve the Industrial Engineering Plan for projects worked on. Well over eight hundred employees are now working at the Longhorn Division and more are being added to the payroll daily. The Longhorn Division has attracted many well qualified technically trained individuals and is recruiting others.

Future

Rarely in any industry are better opportunities offered to professional scientific personnel than that of the rocket industry. Few companies offer a more diversified program with greater benefits than does Thiokol Chemical Corporation.

Quoted in the March 20, 1956, issue of the *Journal of Commerce*, Aaron B. Feigen, security analyst for Josephthal & Co., stated that with the nation's defense program emphasizing guided missiles and rockets, the outlook for Thiokol Chemical Corporation "is good for 1956 and brilliant on the longer term." Current trends at Thiokol facilities point out the truth of Mr. Feigen's prophesy.

For a copy of the Thiokol informative booklet "From Rubber to Rockets" or for information about specific job openings, readers are cordially invited to write to the Personnel Department at either of the following addresses: Thiokol Chemical Corporation, Redstone Division, Huntsville, Ala.; Thiokol Chemical Corporation, Longhorn Division, Marshall, Tex.; Thiokol Chemical Corporation, Elkton Division, Elkton, Md.

Rocket engines are tested to obtain information on thrust, vibration, temperature, and other performance data

Western Gear Corporation

2600 East Imperial Highway
Lynwood, Calif.

MANY fine opportunities are offered qualified engineering graduates these days. But rarely, we believe, are positions offered that will give the engineer the chance to acquire a vast diversification of experience coupled with the opportunity for rapid promotion limited only by his abilities to qualify.

Western Gear Corporation plants have some of the most elaborate and complete research and development laboratories in the electro-mechanical products field. Our new Engineering Building, scheduled for completion this year (*see photo*) will offer the most advanced and modern facilities for the practice of the profession.

A block-long laboratory at our Lynwood Works is exclusively devoted to an active, expanding research and development program. Here highly classified components of aircraft, missiles, rockets are tested and proved. The engineer involved with the project has the opportunity to follow his work from its conception through all its stages of testing and manufacture. Thus he is not limited in the chance to demonstrate his abilities and he can truly be an individualist . . . not just another clock number on a payroll, bottlenecked in a huge engineering personnel group.

While the needs of the aviation industry occupy a major degree of attention, our company is a primary source of mechanical power transmission equipment, largely custom engineered, for the needs of every industry, be it aircraft, atomic power, marine machinery, printing presses, food machinery, electric motors, VHF and UHF antenna systems, or numerous others.

This diversification has helped us build stability, for our growth and expansion are not tied to the economic picture of a single industry. It has also made necessary a heavy concentration of engineers among our personnel. We have instituted on-the-job training programs at full pay to acquaint newcomers with all phases of our business and to enable them to select the job that interests them most, whether it be pure research, design, marketing, or other departments of the company. Attesting to the success of our training program is the fact that many engineering newcomers of the past five years are now in important supervisory positions. Specialized engineering courses are regularly offered to interested personnel, covering a wide variety of subjects.

Western Gear has big plans for the future, but this doesn't mean that we are an immature and unrecognized company at present. Quite the contrary. Although our roots are in the West, we rank as one of the nation's top custom engineering firms in the mechanical power transmission field, with 68 years of experience to back us up.

We operate six plants located in the cities of Lynwood, Belmont, Pasadena, and San Francisco, Calif., and Seattle and Houston. Thus you can select the area and climate that appeals to you most. A full program of worth-while employee benefits is offered.

So, if you seek broad experience and a job that is a constant challenge to you, why not further explore the possibilities that exist at Western Gear Corporation plants? You may contact the Personnel Managers of any of our plants direct if you wish or write:

Personnel Director
Western Gear Corporation
P. O. Box 192
Lynwood,
Calif.

AMERICAN ROCKET SOCIETY

500 Fifth Ave., New York 36, N. Y.

A national association for the advancement of rocketry, jet propulsion, and astronautics

Aims and Functions

THE AMERICAN ROCKET SOCIETY is a national association of engineers and scientists devoted to "the development and application of the principle of jet propulsion as applied to rockets, aircraft, water and underwater craft and to all other appropriate and practical devices" and to "the development of the sciences and engineering techniques pertaining thereto" such as instrumentation, guidance and control, high temperature materials, upper atmospheric research, aerodynamics, structures, combustion, fuels and propellants, heat transfer, etc. ARS has always maintained a deep interest in responsible scientific study of space flight and in fostering sound professional and public interest in this subject. The Society carries out its aims through:

1. Section Meetings, held periodically at most of the centers of rocket and jet propulsion activity throughout the country. Sections are self-governing and programs are both technical and social.

2. Regional Meetings, which include technical sessions as well as field trips to rocket, guided missile and aircraft establishments, observatories, etc. These meetings are often held in cooperation with other technical societies.

3. The Annual ARS Convention. Held in conjunction with the ASME Convention, this gathering includes technical sessions during which original papers are presented on all aspects of the Society's interests. Outstanding guest speakers are presented at luncheon and dinner meetings and the ARS Awards are presented. Awards include the Robert H. Goddard Memorial Award for work in liquid propellants, the C. N. Hickman Award for solid propellants, the James H. Wyld Memorial Award for outstanding application of rocket power, the ARS Astronautics Award for contribution to the advance toward space flight, the G. Edward Pendray Award for rocket and jet propulsion literary effort, and the ARS Student Award for the best student paper on rocket and jet propulsion. Fellowships are also presented at this meeting to leading figures in the field.

The ARS Library, located in New York, contains historical as well as current material relating to rocket progress.

An affiliation exists between the American Rocket Society and the American Society of Mechanical Engineers which permits ARS members to use the Engineering Library in New York, attend ASME Sectional and National meetings and allows the purchase of reprints of articles at member rates.

History and Accomplishments

ARS was organized on March 21, 1930. During its early years, experimental rocket firings were made, and from them evolved data and equipment which led to the development of several significant rocket engines, as well as to the formation of industrial enterprises which today hold distinguished places in the field.

As progress in rocket and jet propulsion became more rapid, and demands from the military mounted, the Society devoted itself exclusively to dissemination of information through meetings and publications.

Dr. Robert H. Goddard was one of the early members of the society, as were many other pioneers who now hold key positions in industry, science, education and government.

Membership

Four types of membership are open in the society:

MEMBER: Members shall consist of engineers and scientists who are actively engaged in the development or application of rocket or jet propulsion, other persons who have been working on the development or application of rocket or jet propulsion for at least four years and who hold or have held responsible positions in these fields, and such persons as may be deemed eligible for this class of membership by the Board of Directors by virtue of their outstanding accomplishments in other fields and their unusual interest in the purposes of the Society.

ASSOCIATE MEMBER: Associate members shall be persons, other than students, who are actively interested in the development or application of rocket or jet propulsion.

STUDENT MEMBER: Student members shall be persons not less than 17 years of age whose principal occupation is study at a recognized educational institution or who are serving as enlisted personnel in the Armed Forces of the United States, and who are interested in the development or application of rocket or jet propulsion.

CORPORATE MEMBER: Corporate Members shall be educational, scientific or industrial organizations who may choose this method of expressing their interest in the development or application of rocket or jet propulsion, and who are considered acceptable by the Board of Directors. Each Corporate Member shall be entitled to five representatives with the rights and privileges of Members.

Subscriptions to the Journal without membership are available at the rate of $12.50 per year.

Certificates of membership are sent to each member upon acceptance. Identification pins may be purchased for $2.00 from the office of the Secretary.

Publications

JET PROPULSION, Journal of the American Rocket Society, is published monthly and mailed to all members. Edited by distinguished scientists, the Journal is recognized as the most complete and authoritative source of original technical material on rocketry, jet propulsion, astronautics, and allied sciences.

It also includes feature articles on industry, government, and university activities, news items, and ARS happenings. It carries a calendar of coming meetings, a digest of books and articles published on rocket and jet propulsion in this country and abroad, and reviews by authorities on current books.

Information on advertising rates for the Journal can be obtained from the Secretary.

BOOKS AND TECHNICAL PAPERS. The Society makes available to its members at special rates, technical papers, reprints and other useful information bearing on jet propulsion, rockets and their application. It also has available back issues of the Journal and its predecessor, Astronautics.

A list of such material currently available may be obtained by writing to the office of the Secretary.

PLEASE USE FORM ON REVERSE SIDE TO APPLY FOR MEMBERSHIP

APPLICATION FOR MEMBERSHIP • AMERICAN ROCKET SOCIETY

To the Membership Committee:

FOR OFFICE USE ONLY
No.
Adm.
Ref.
Cert.

I hereby apply for membership in the American Rocket Society, Inc. and enclose $......... as my annual membership dues, $5.00 of which is for a year's subscription to the Journal of the American Rocket Society. The information given herewith is correct to the best of my knowledge.

Check type of membership desired

- ☐ MEMBER—Annual Dues $15.00
- ☐ ASSOCIATE MEMBER—Annual Dues $10.00
- ☐ STUDENT MEMBER—Annual Dues $5.00

Date.........................

Signature in Full..
(Sign with pen—Do not use initials)

(PLEASE PRINT OR TYPE)

PERSONAL INFORMATION

Name.. Title..............................

Organization..

Services or products of organization...

Your duties and responsibilities..

....

Organization Address...☐
Home Address...☐
Check Address for Society Mail

Age..........Date of Birth....................Country of Birth....................Citizen of....................

Other Technical Organization Memberships...

....

EDUCATIONAL RECORD

Secondary School.. Date.........................

College or University.. Date.........................

Major Subject..............................Degree Received.................. Date.........................

Names of other Technical Schools or Colleges..

Additional Degrees..........................By Whom Conferred.............. Date.........................

REFERENCES (Name three and include addresses)..

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PROFESSIONAL RECORD

DATES: From	To	Names and addresses of past employers. Your positions, duties and responsibilities.
		(If space is inadequate add supplementary sheet of this size)